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(12) **United States Patent**
Wensley et al.

(10) **Patent No.: US 11,089,660 B2**
(45) **Date of Patent: Aug. 10, 2021**

(54) **ELECTRONIC VAPORIZATION DEVICES**

(71) Applicant: **Fontem Holdings 1 B.V.**, Amsterdam (NL)

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(73) Assignee: **FONTEM HOLDINGS 1 B.V.**, Amsterdam (NL)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 402 days.

(21) Appl. No.: **15/004,431**

(22) Filed: **Jan. 22, 2016**

(65) **Prior Publication Data**

US 2016/0213065 A1 Jul. 28, 2016

Related U.S. Application Data

(60) Provisional application No. 62/106,679, filed on Jan. 22, 2015, provisional application No. 62/153,463, (Continued)

(51) **Int. Cl.**
H05B 3/46 (2006.01)
H05B 1/02 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H05B 3/46*** (2013.01); ***A24F 40/46*** (2020.01); ***A24F 40/48*** (2020.01); ***A24F 40/485*** (2020.01);
(Continued)

(58) **Field of Classification Search**
CPC B44C 7/027; D06F 75/30; D06F 87/00
(Continued)

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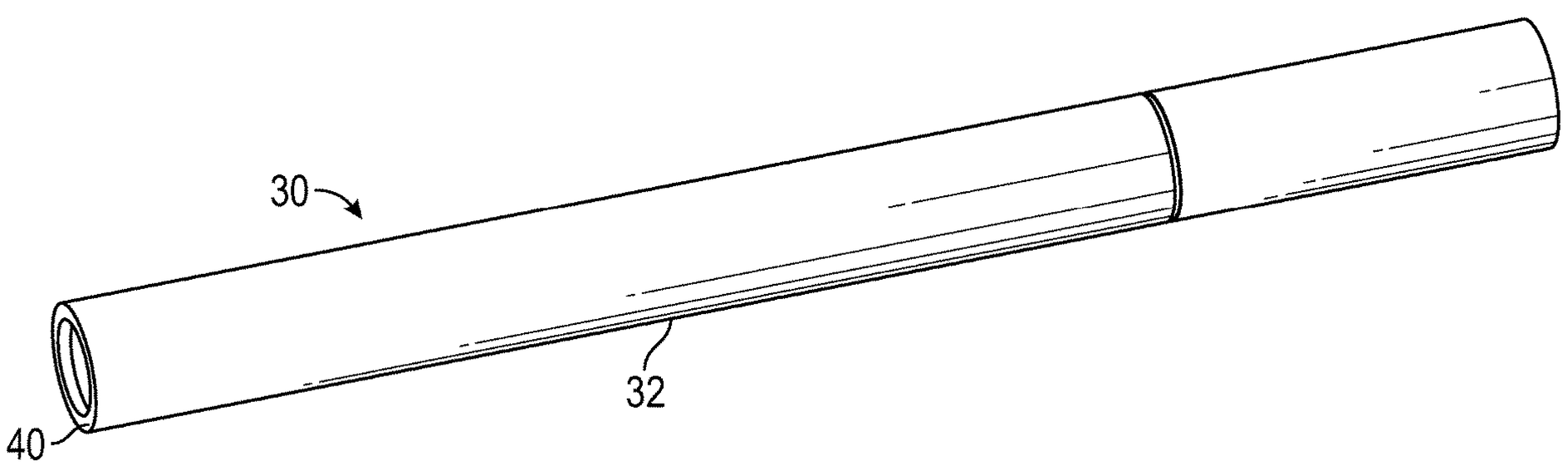
(74) *Attorney, Agent, or Firm* — Perkins Coie LLP; Kenneth H. Ohriner

(57) **ABSTRACT**

A device for generating a condensation aerosol includes vaporization chamber having an upstream first inlet and a downstream outlet. A tube supplies liquid to a heater in the vaporization chamber. The liquid is pumped out of the tube and onto the heater, which vaporizes the liquid. Air flows from inlets through the vaporization chamber, and generally perpendicular to the tube. The vaporized liquid is entrained in the air, forming a condensation aerosol having a particle size in a selected range. A second inlet provides a substantially laminar flow of air into the airflow path, wherein the second inlet is downstream of the heater; and the device capable of changing air flow in the vaporization chamber to change the particle size of the condensation aerosol and/or to change the amount of visible vapor emitted from the device.

16 Claims, 11 Drawing Sheets



Related U.S. Application Data

filed on Apr. 27, 2015, provisional application No. 62/192,377, filed on Jul. 14, 2015.

(51) **Int. Cl.**

H05B 3/16	(2006.01)
A24F 40/46	(2020.01)
A24F 40/48	(2020.01)
A24F 40/485	(2020.01)
A24F 40/50	(2020.01)
A24F 40/10	(2020.01)

(52) **U.S. Cl.**

CPC ***A24F 40/50*** (2020.01); ***H05B 1/0244*** (2013.01); ***H05B 3/16*** (2013.01); *A24F 40/10* (2020.01)

(58) **Field of Classification Search**

USPC 128/200.14, 203.17, 203.36; 392/390, 392/391, 399, 404; 219/483, 497; 700/266

See application file for complete search history.

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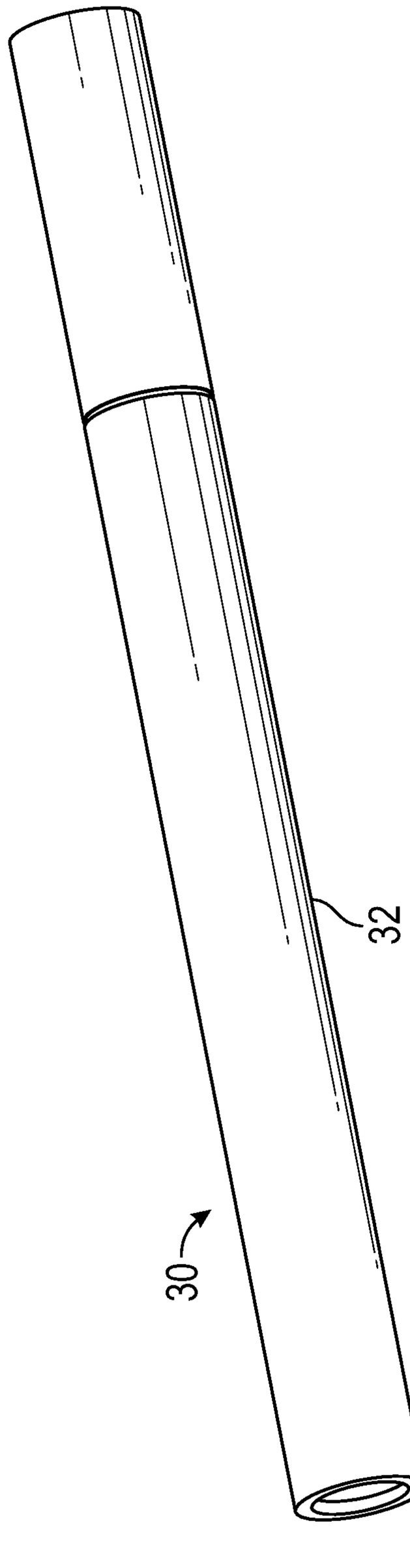


FIG. 1

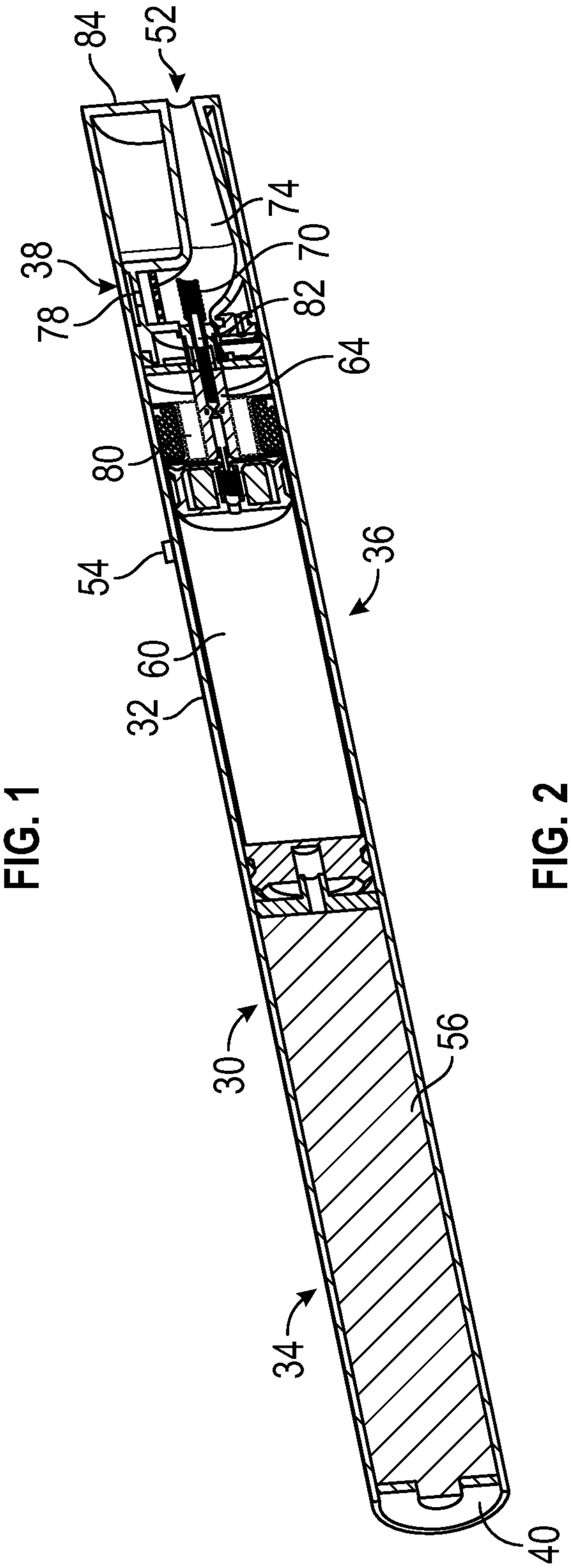
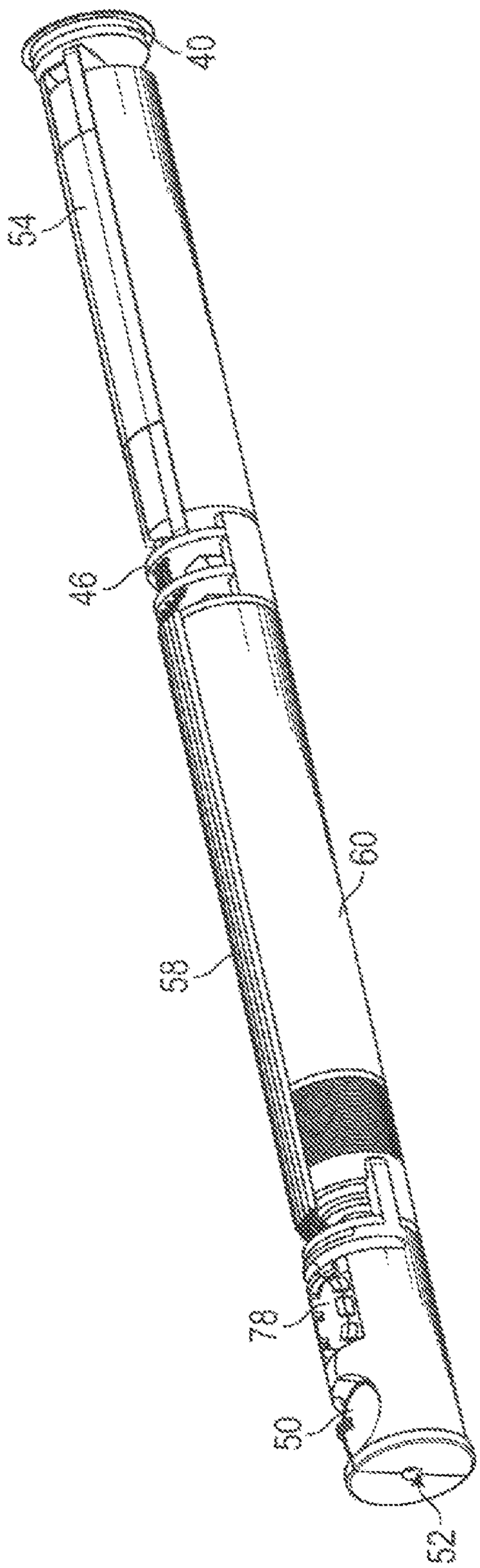


FIG. 2



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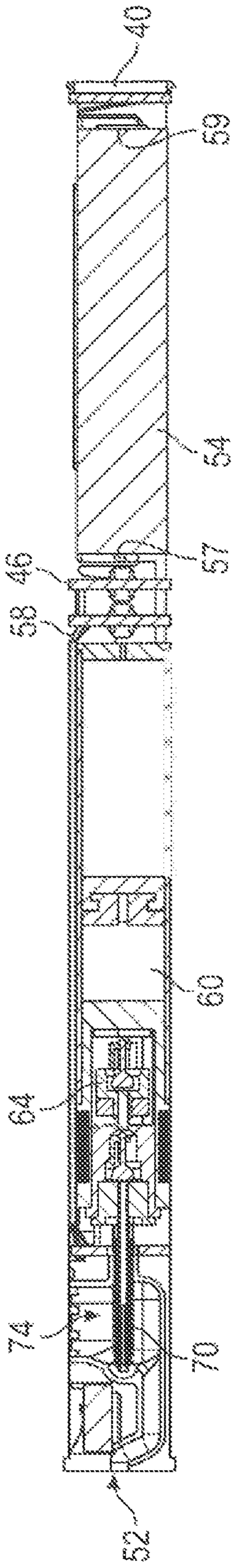

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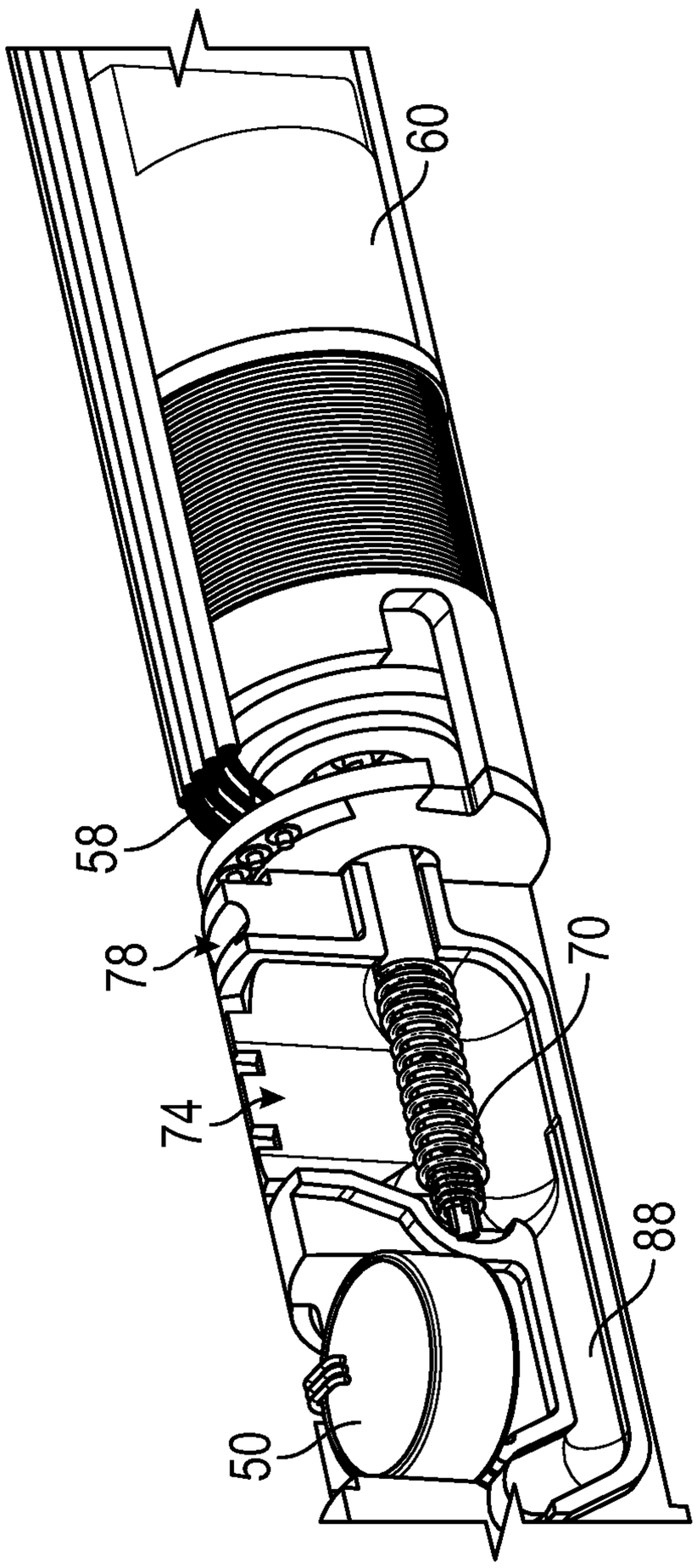
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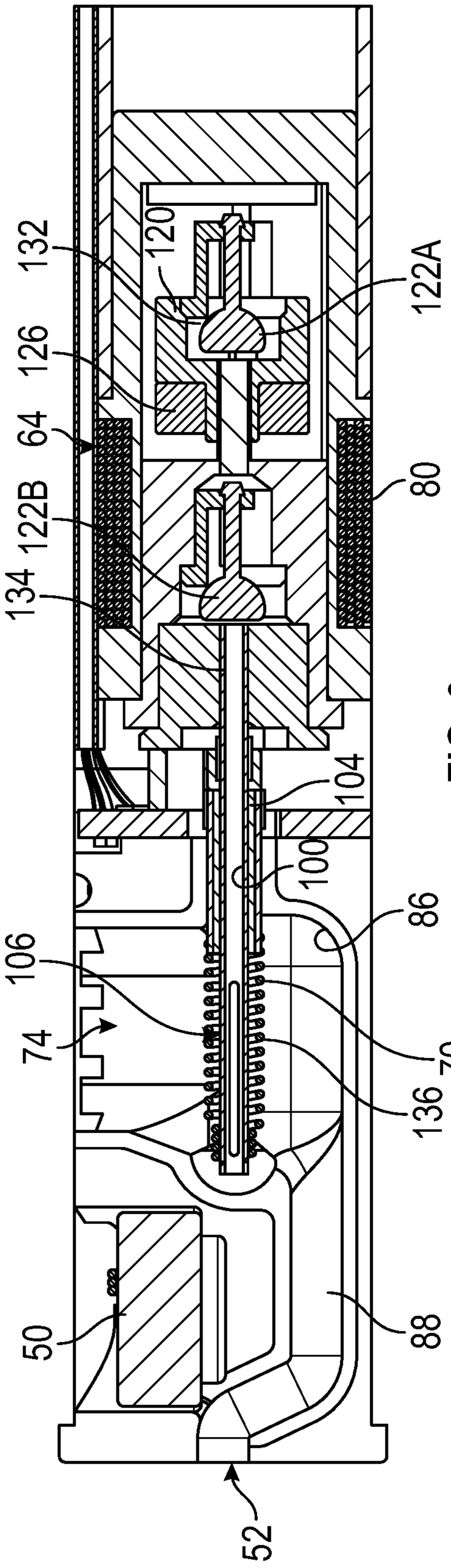
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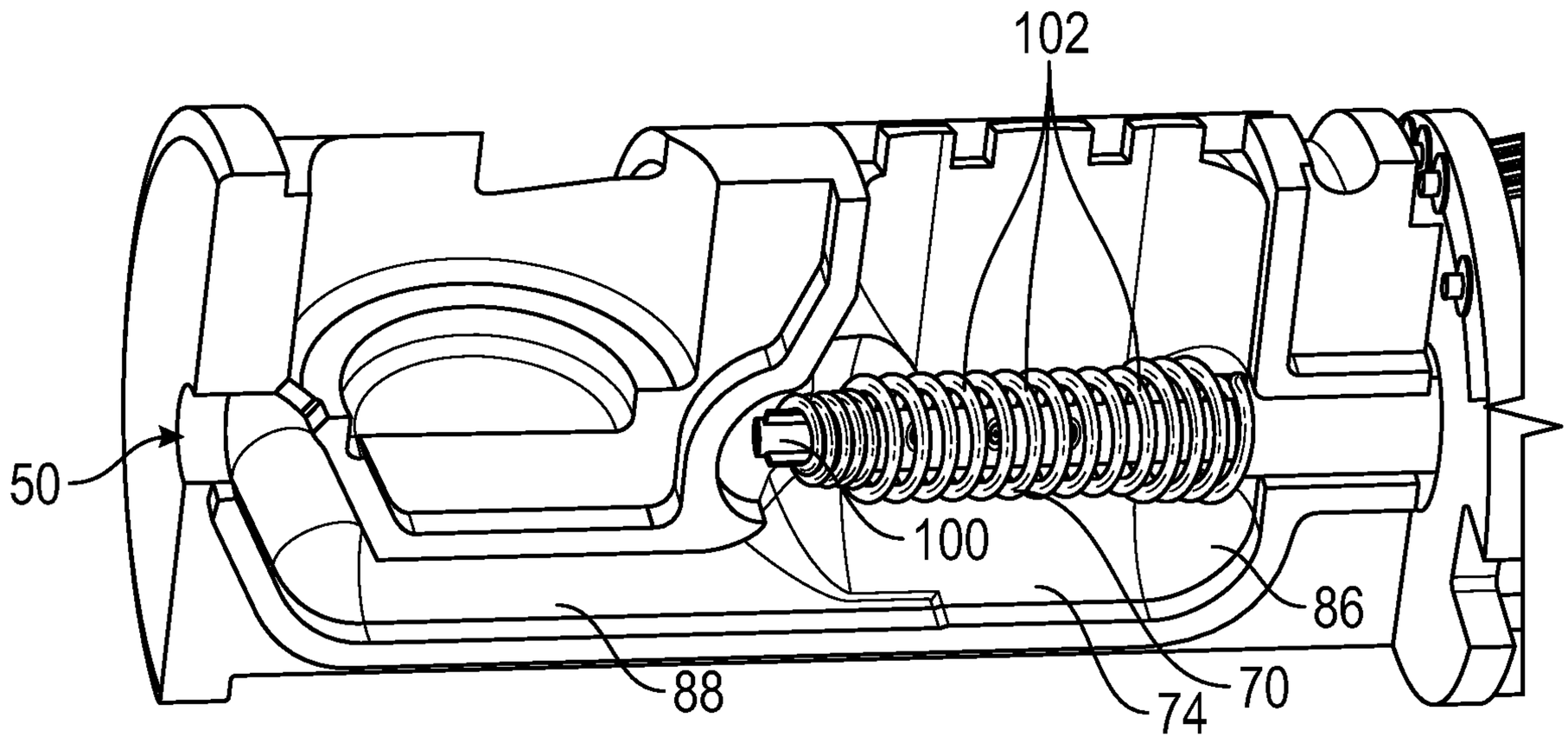
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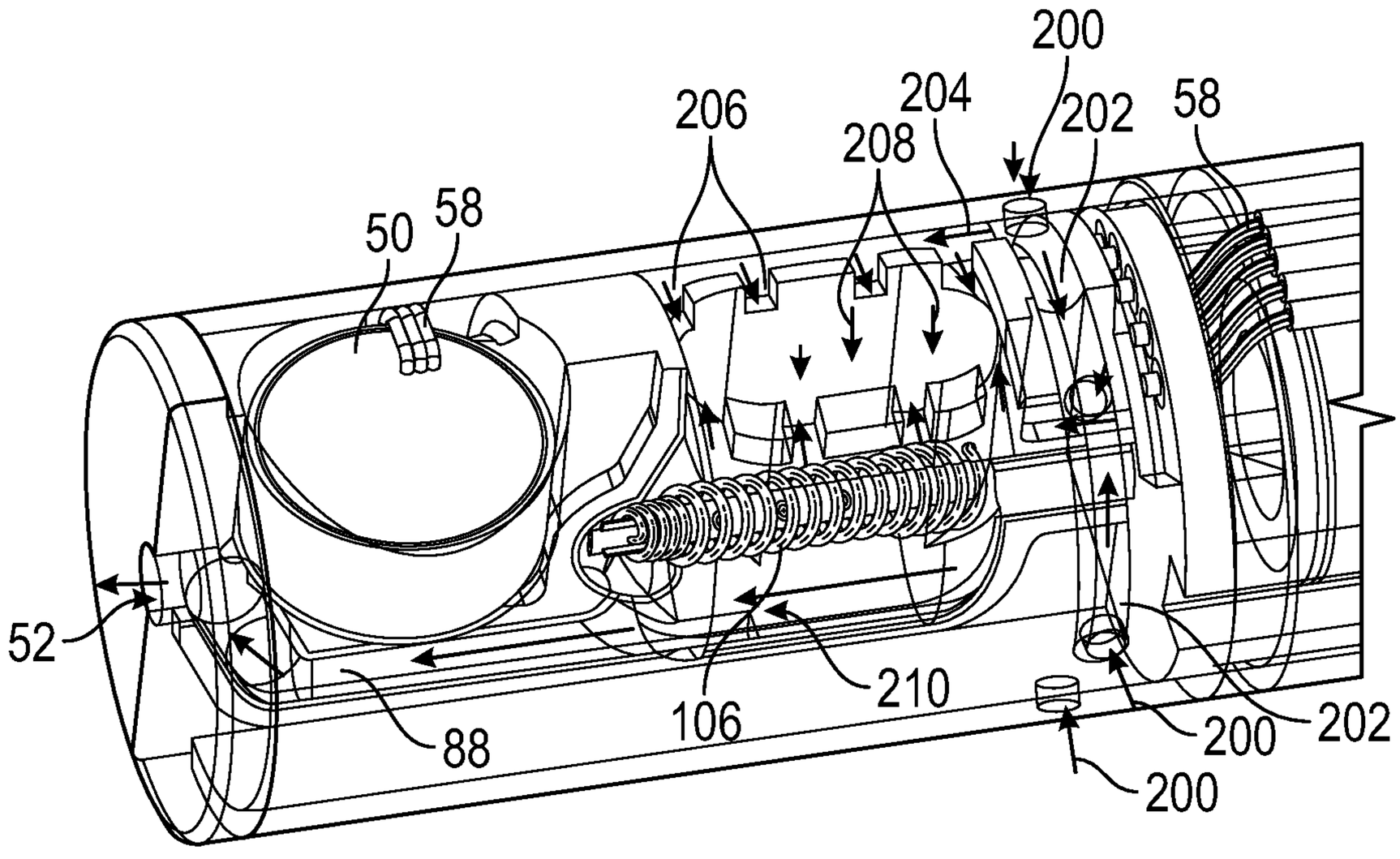
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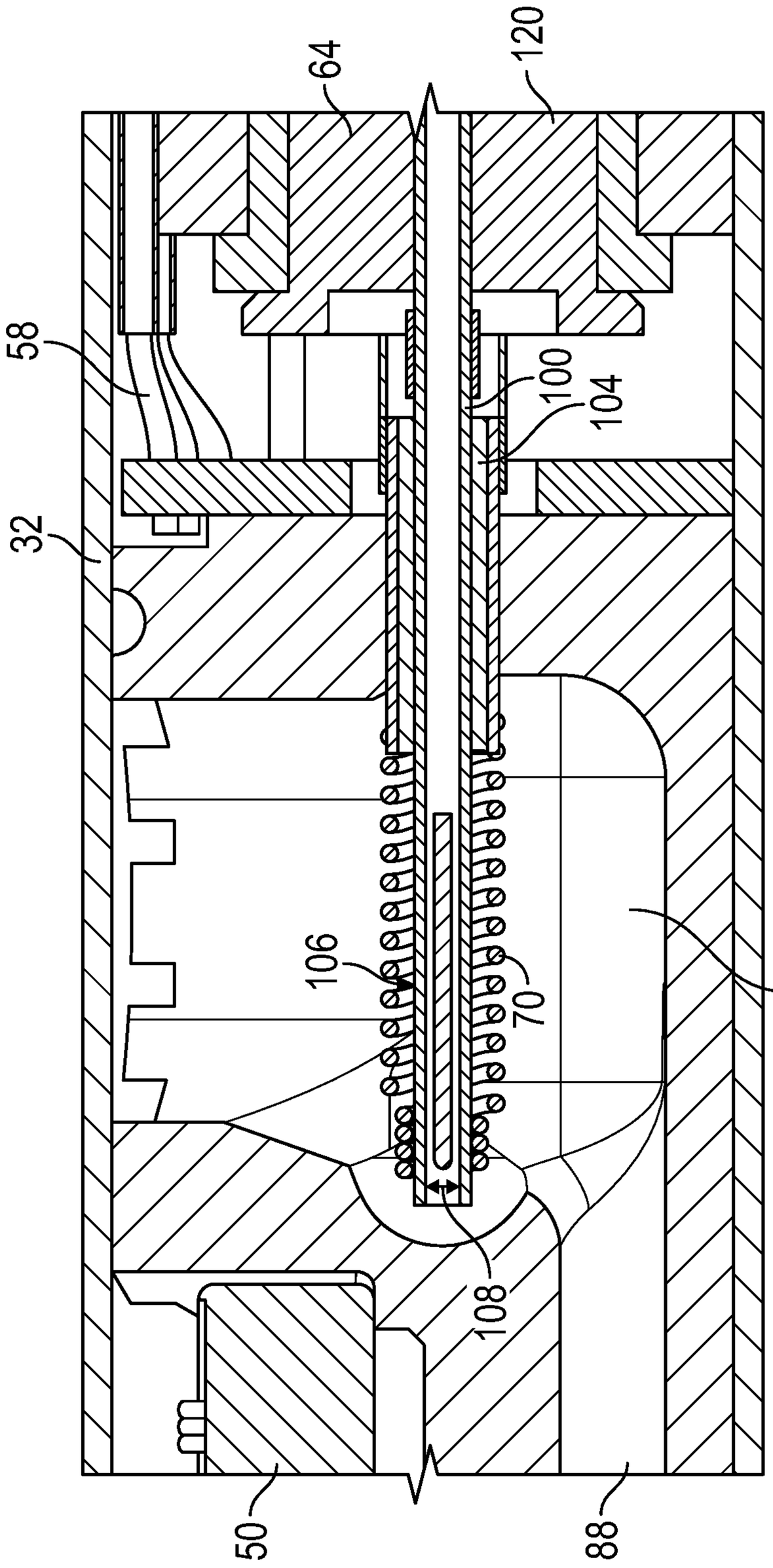

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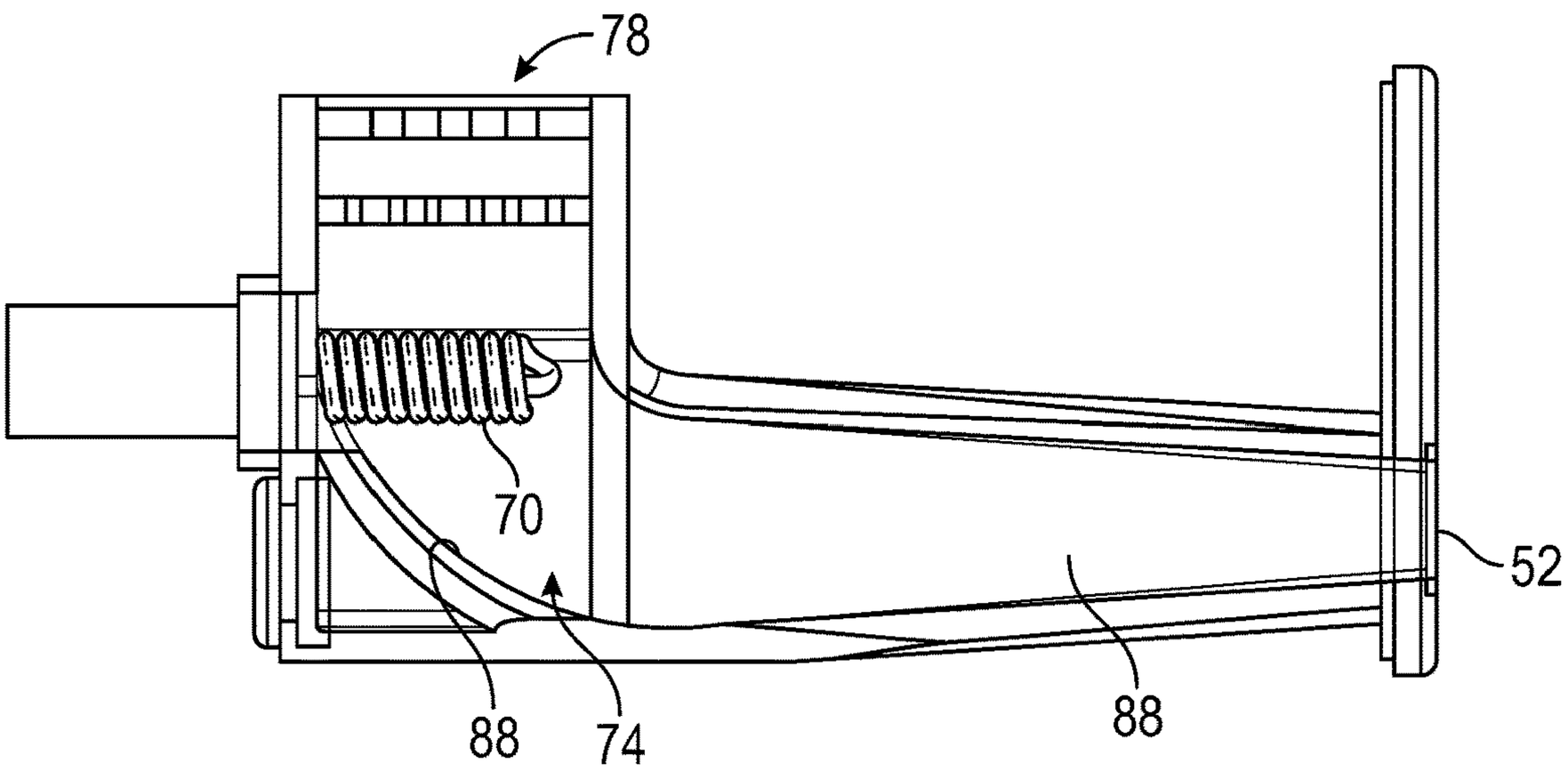

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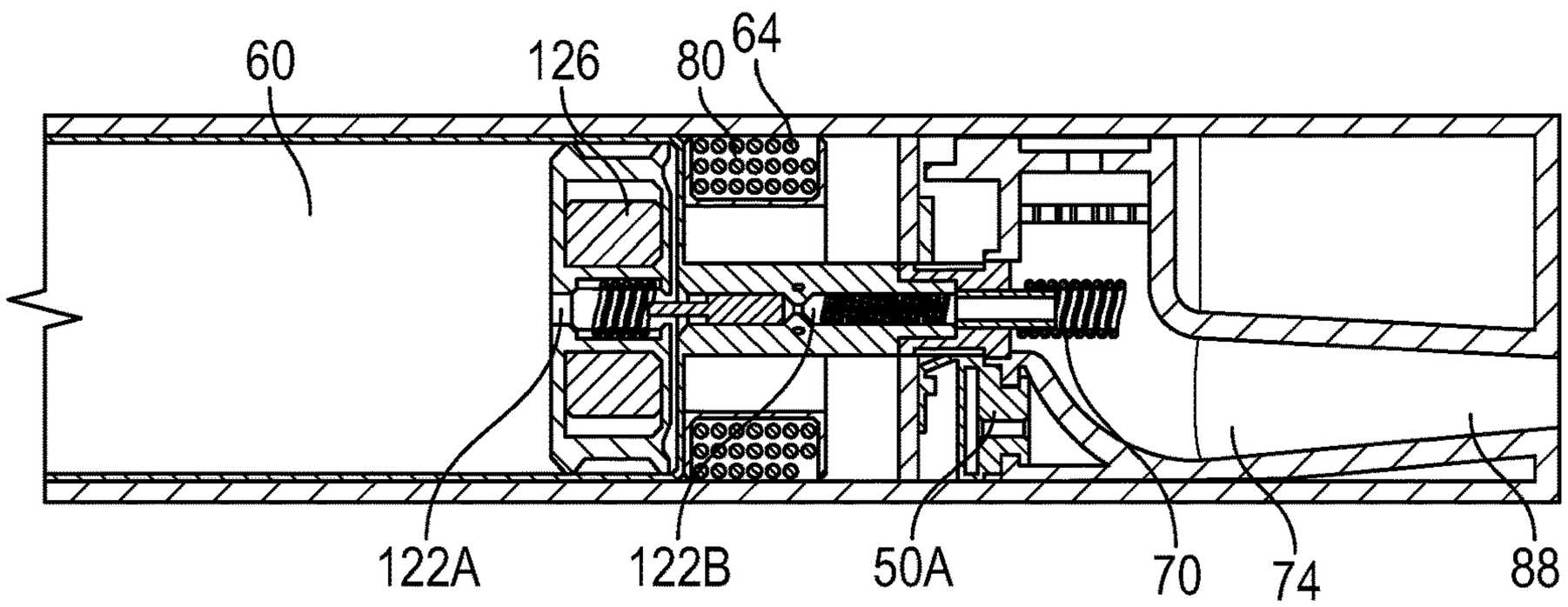

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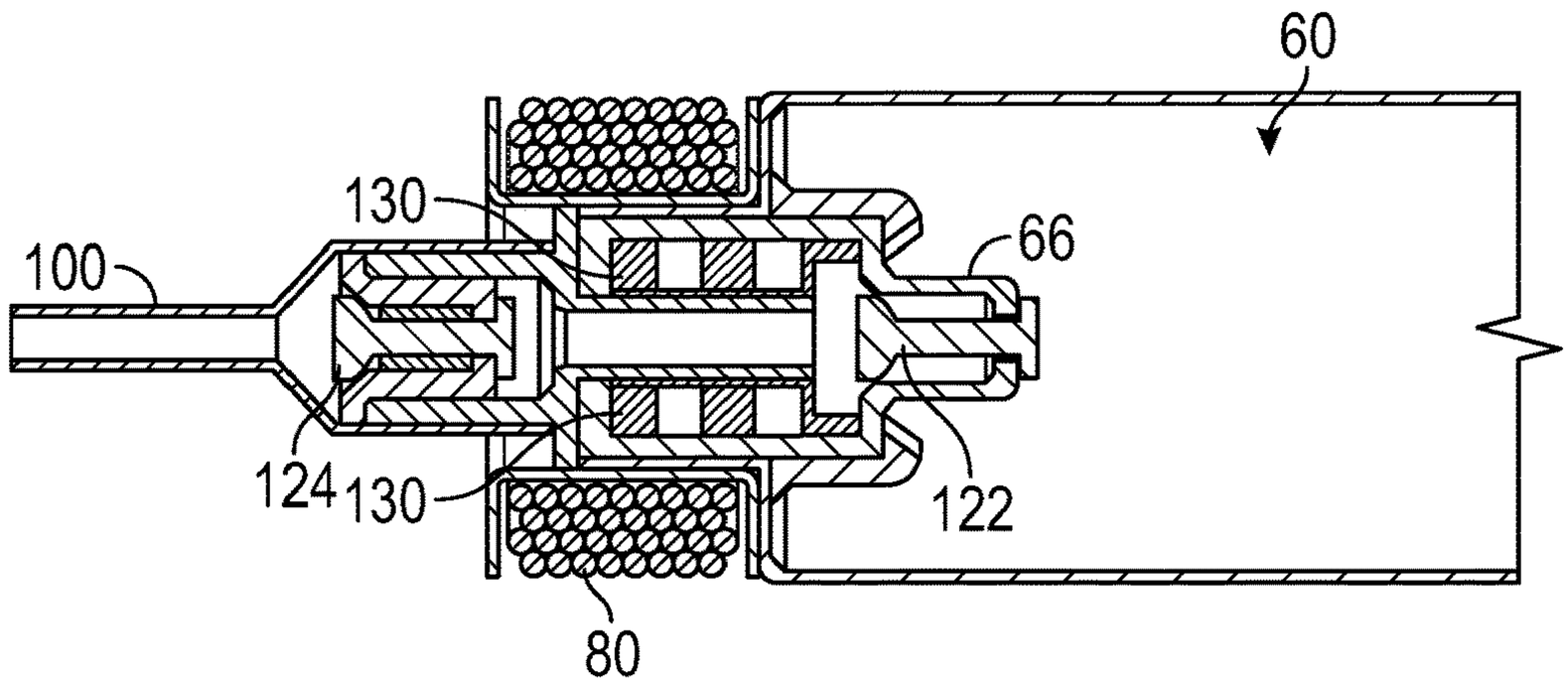

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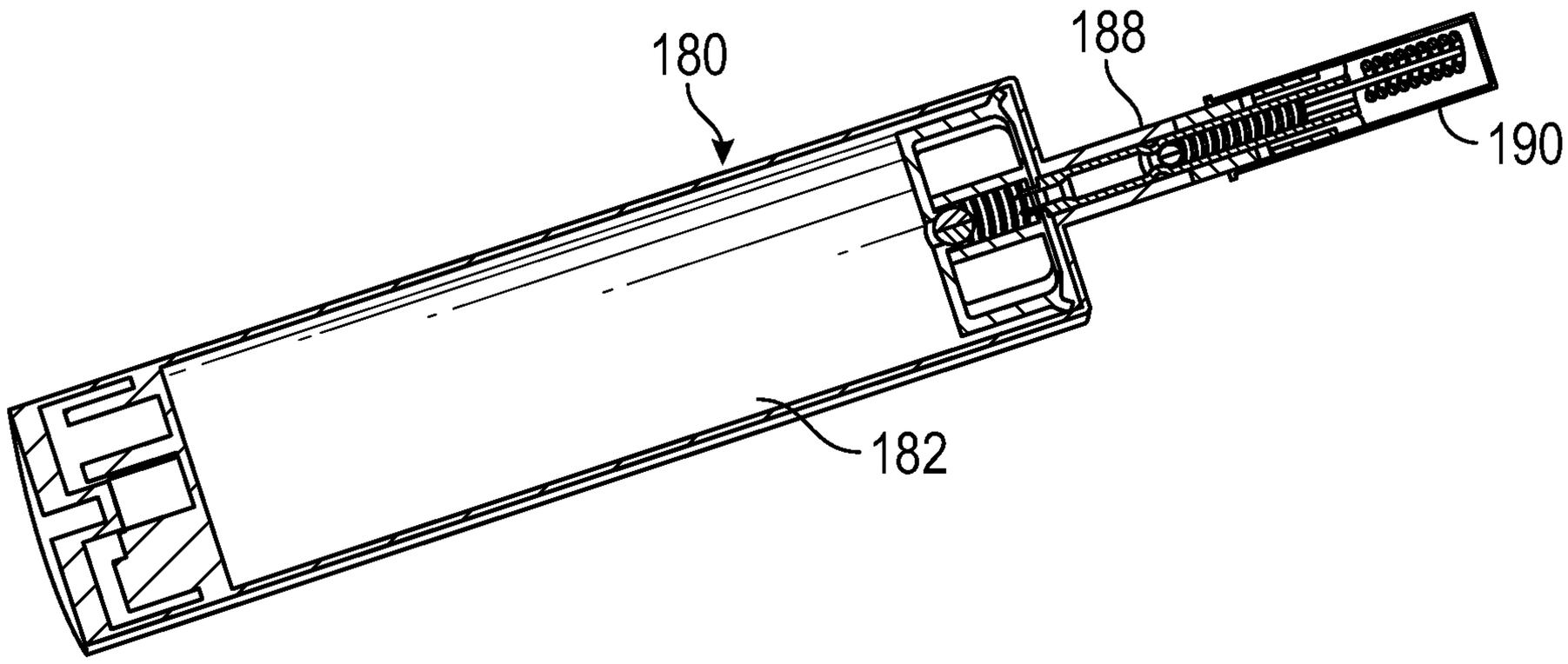

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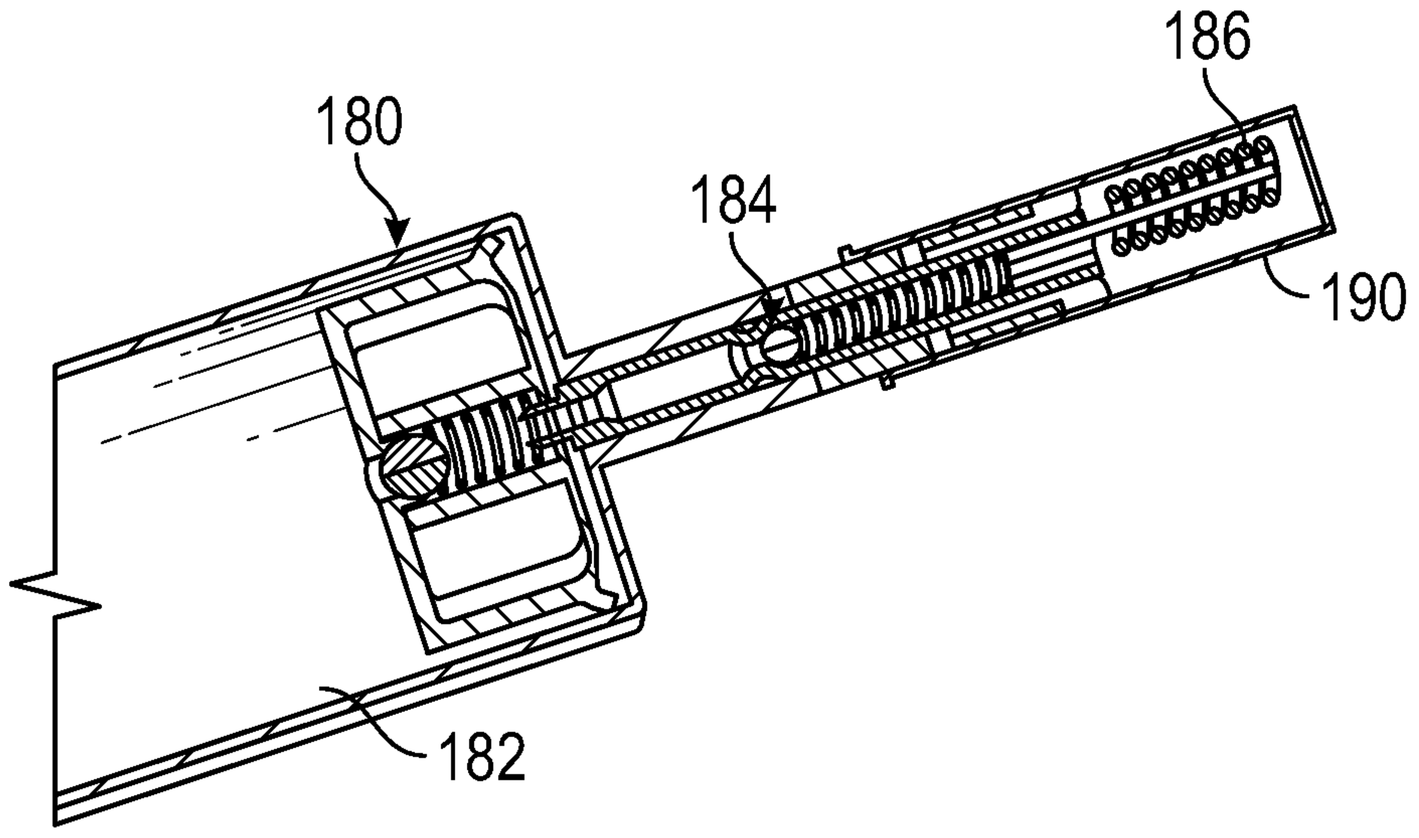

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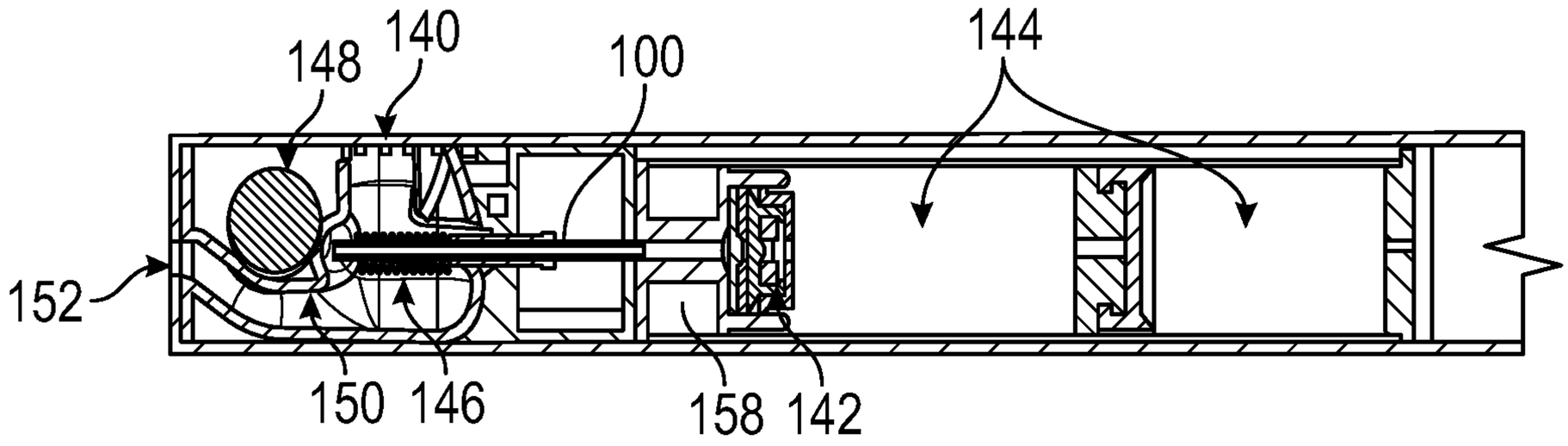
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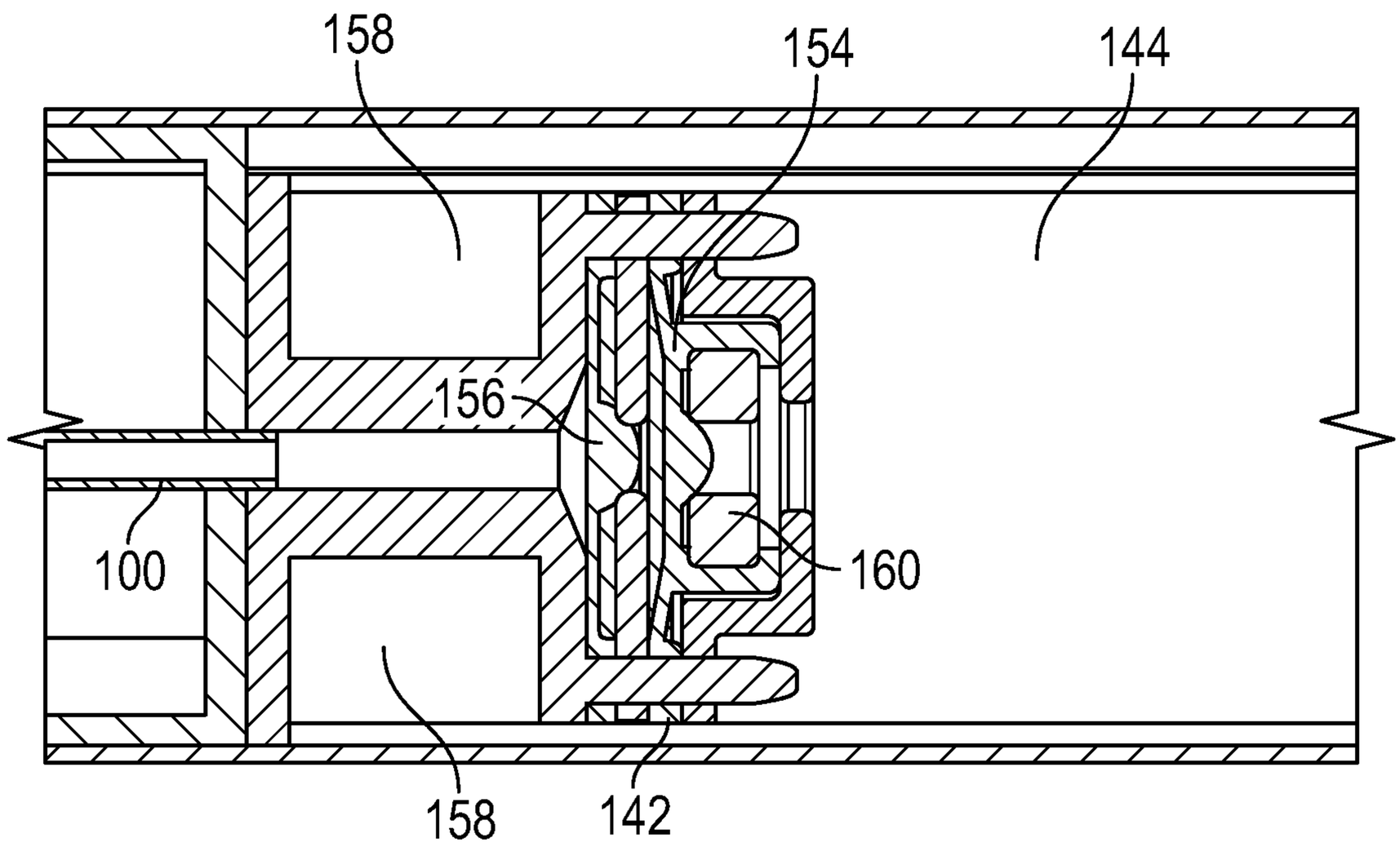
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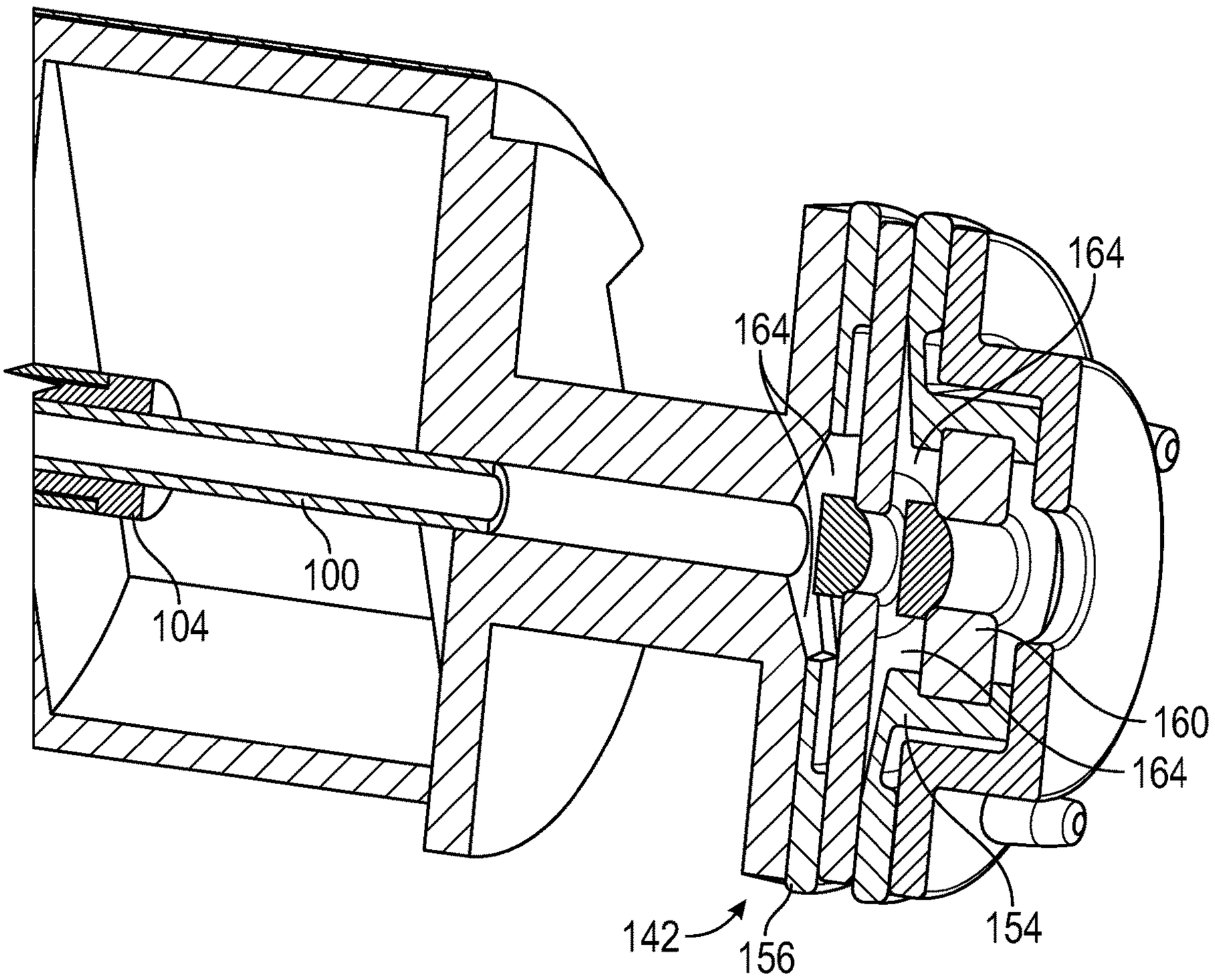
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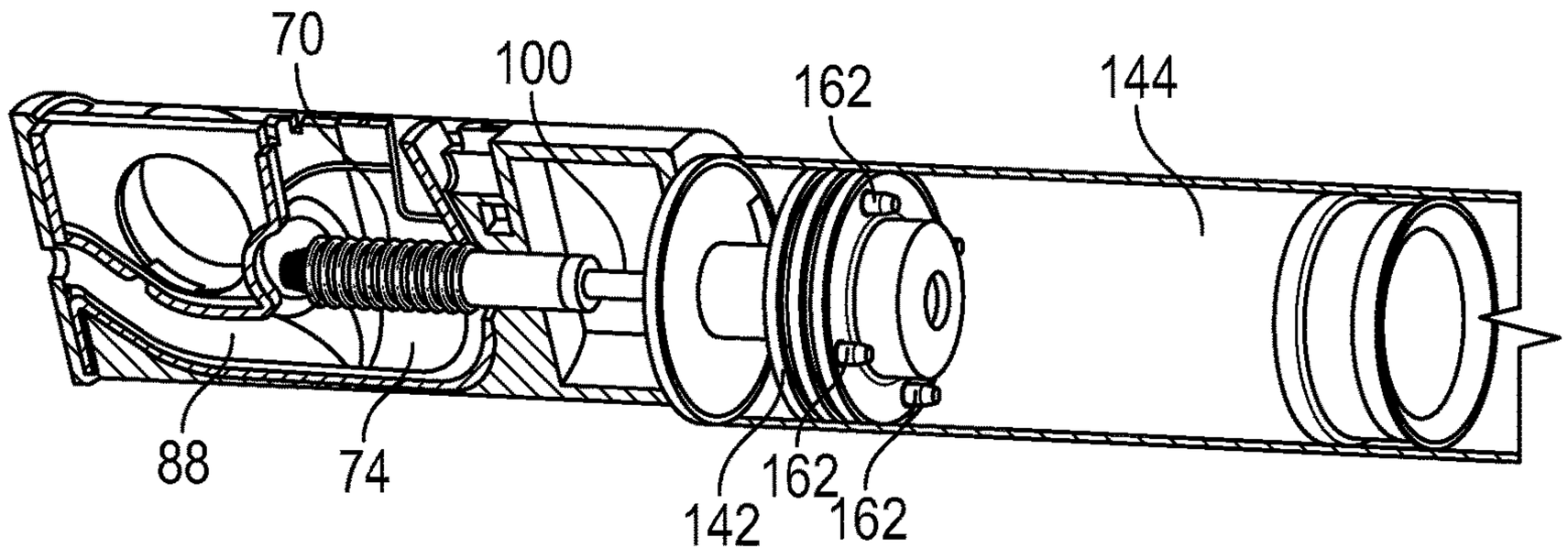
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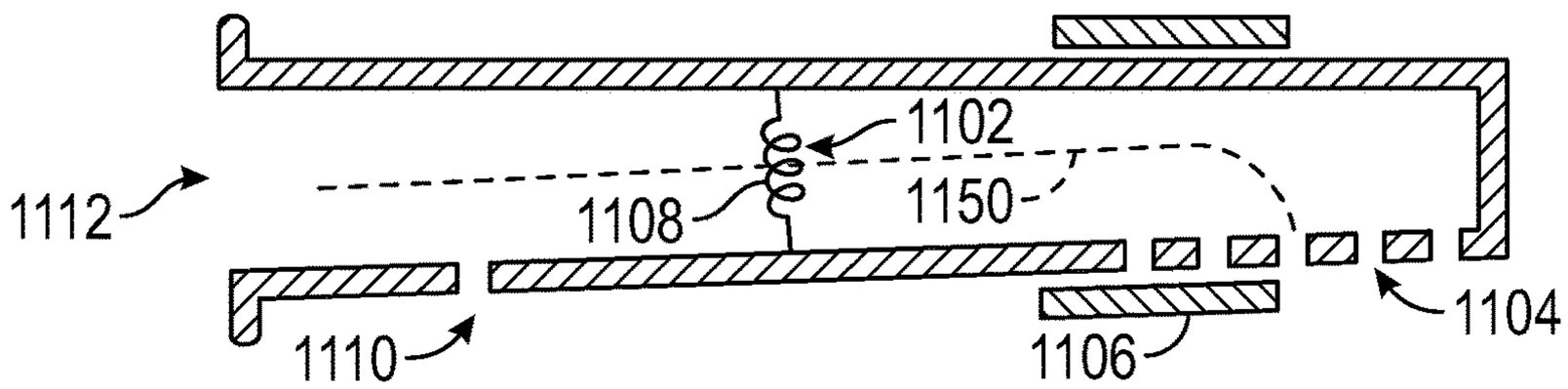
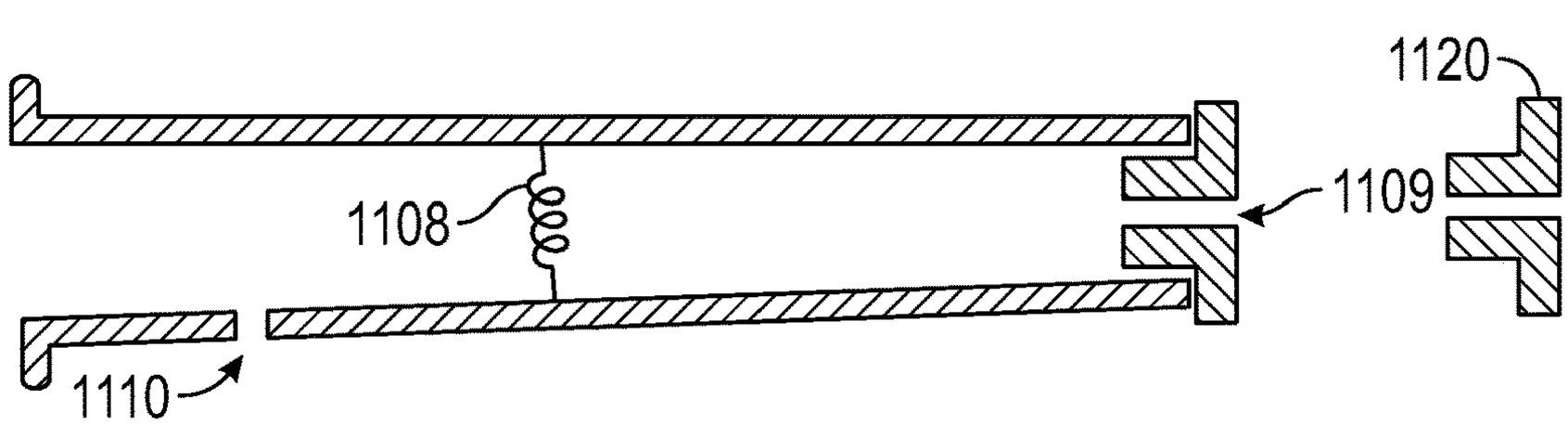


FIG. 19



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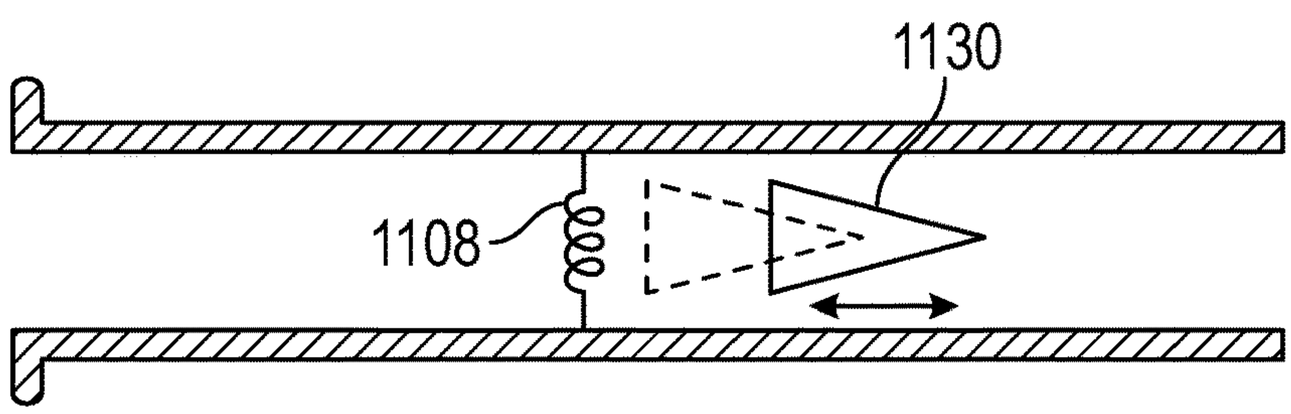

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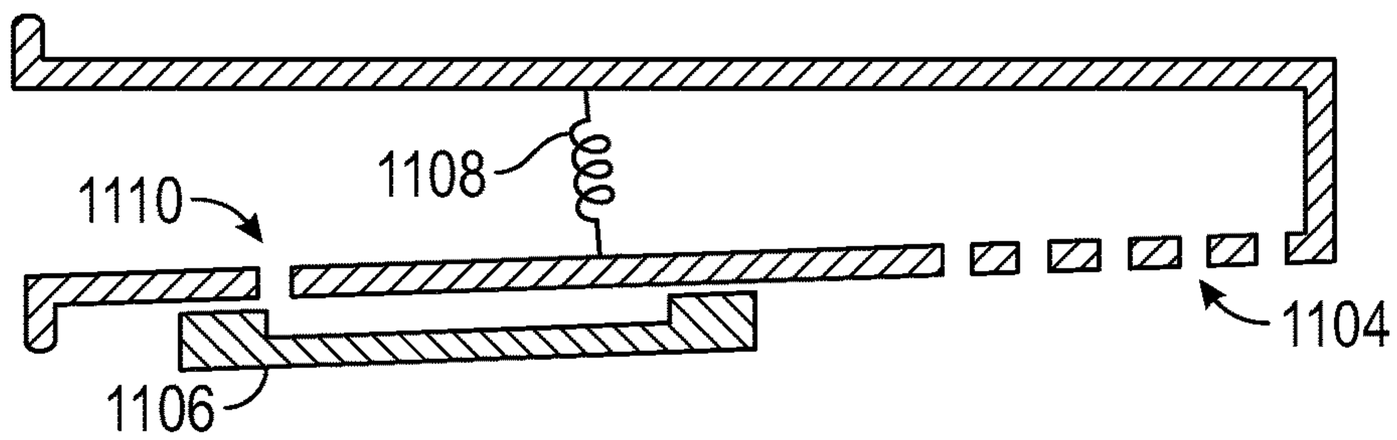

FIG. 22

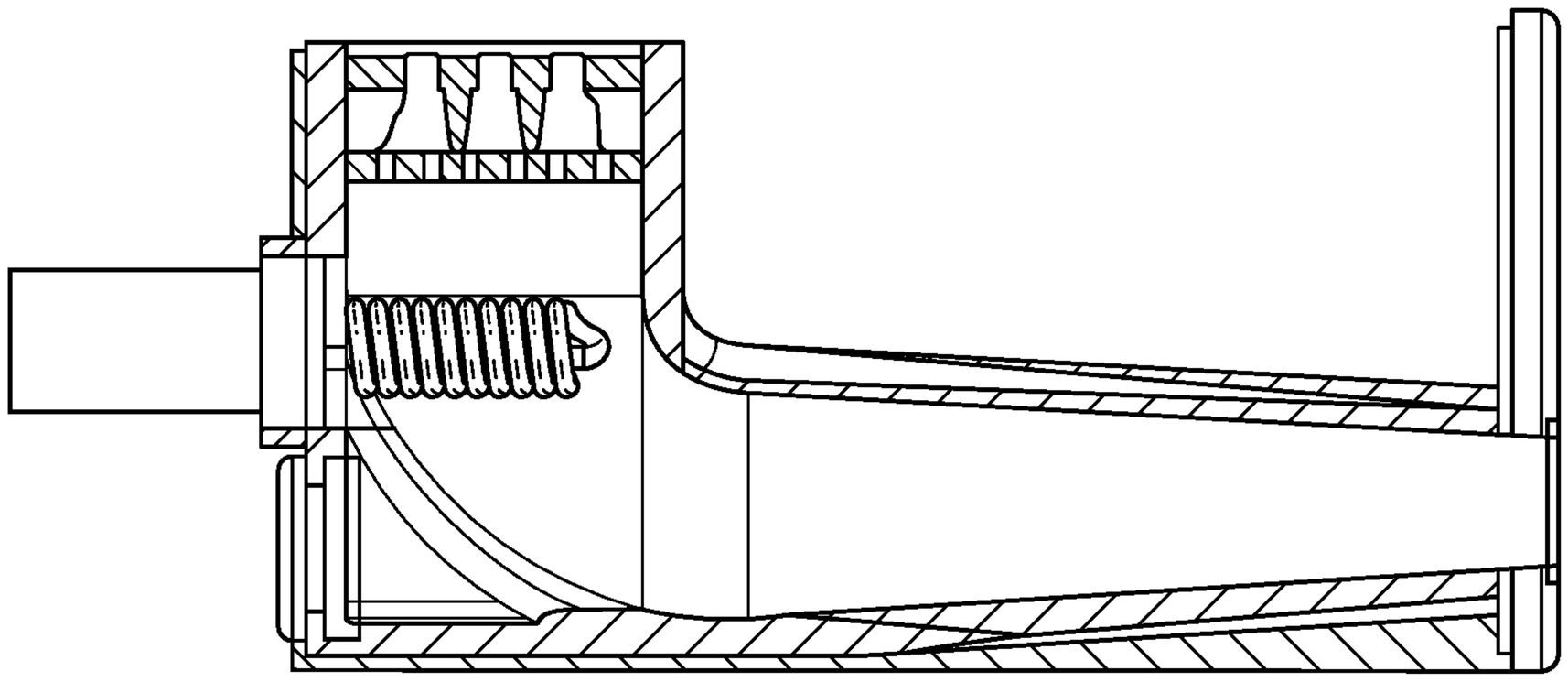

FIG. 23

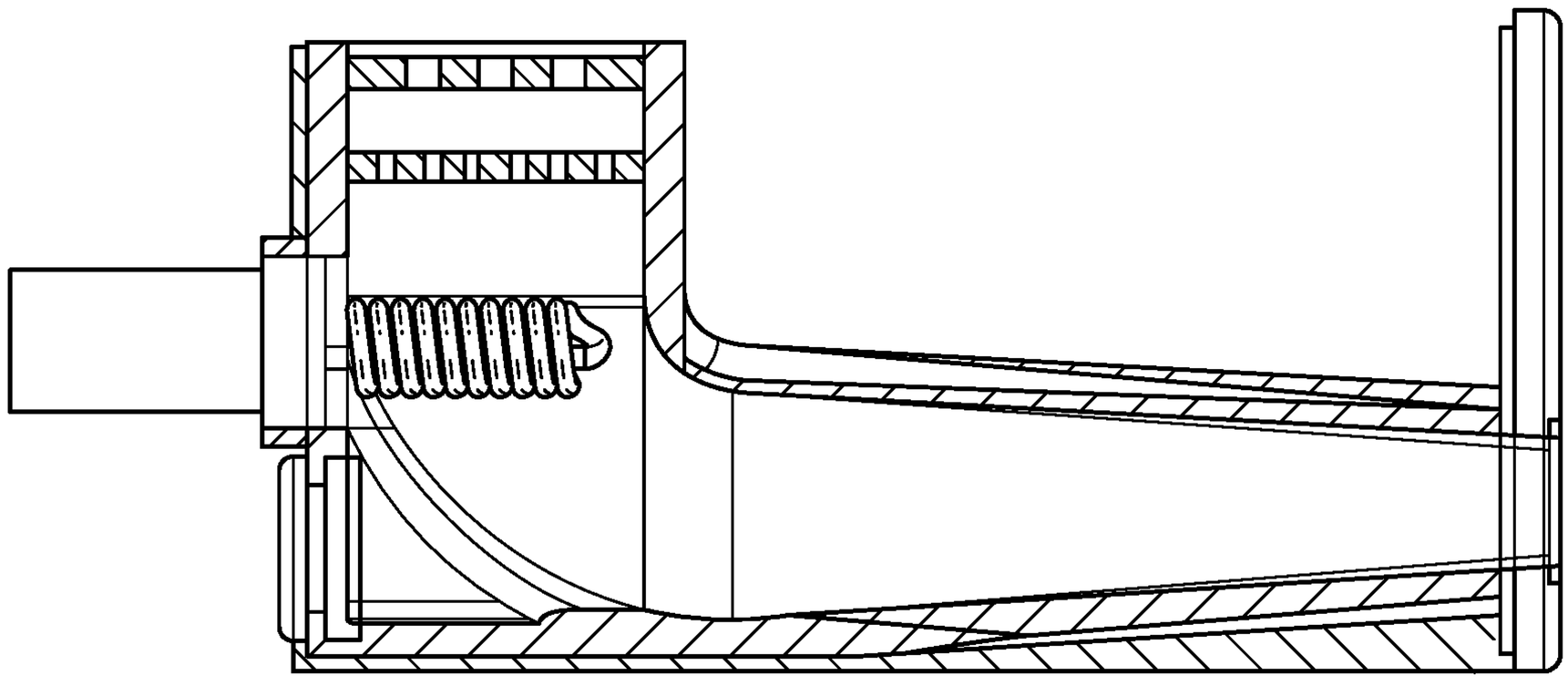

FIG. 24

ELECTRONIC VAPORIZATION DEVICES

CROSS-REFERENCE TO RELATED APPLICATION(S)

This application claims priority to U.S. Provisional Patent Application Nos. 62/106,679, filed Jan. 22, 2015; 62/153,463, filed Apr. 27, 2015; and 62/192,377 filed Jul. 9, 2015 and incorporated herein by reference.

BACKGROUND OF THE INVENTION

Multiple factors can contribute to tobacco cigarette addiction. Some of the factors include addiction to nicotine or psychological factors including the smell, taste, or social associations of tobacco cigarette smoking. One factor that can drive cigarette addiction is the sensory cues associated with the inhalation and exhalation of smoke itself. Some electronic cigarettes create a large amount of vapor to simulate tobacco cigarette smoke. To avoid vapor deposition in the lung and to preclude exhalation of the vapor, some known devices provide aerosol particles between 0.2 microns and 0.6 microns. Aerosol particles in this size range can be too small to gravitationally settle in the lung during regular breathing. Consequently, they tend to be inhaled and then are subsequently exhaled.

Smokers can exhibit a wide range of inhalation profiles. Variation exist among smokers in inhalation rates and the total volume inhaled. Inhalation rates can also vary in different ways from the peak inhalation rate that the smoker achieves to the actual profile (e.g. an inhalation rate that starts slow compared to one that starts rapidly. The efficiency of deep lung deposition can be dependent on many factors such as aerosol particle size, the timing of the delivery of the aerosol to the lung (where in the inhalation volume—early vs. late) and inhalation rates. Inhalation profiles can also affect where aerosols are deposited in the respiratory tract. A more rapid inhalation rate can cause larger aerosol particles to deposit in the back of the throat, mouth and upper airway due to inertial impaction. Shallow breathers, with lower total inhalation volumes, can benefit from aerosol delivered earlier in the inhalation volume, allowing the aerosol to be chased into the deep lung without leaving aerosol in the mouth, throat and upper airway.

These factors create engineering challenges in designing an electronic cigarette or other vaporization device that replicates the tobacco cigarette smoking experience. There is a need for new methods and devices for administering compounds, such as nicotine, to a user. In particular, there is a need for methods and devices for delivery of compounds to a user where the compounds are aerosolized to fall within a specified particle size range. For example, there is a need for improved methods and devices to deliver nicotine to a user in specified doses and in a specified particle range size without the carcinogens and other chemicals associated with tobacco products.

SUMMARY OF THE INVENTION

A device for generating a vapor or condensation aerosol has a heater, such as a wire coil, around a tube in a vaporization chamber between an upstream inlet and a downstream outlet. A reservoir in the device holds a liquid. A pump supplies liquid from a reservoir into the tube. The liquid, which may include nicotine, flows onto the heater via outlets in the tube. The vaporization chamber is part of an airflow passageway which may be configured to produce a condensation aerosol having a particle diameter from about 1 μm to about 5 microns.

The pump may optionally be completely or partially within the reservoir, or the pump may have a drive motor located outside of the reservoir. The drive motor may operate with a solenoid coil magnetically coupled to one or more magnets within the pump.

The airflow path through the vaporization chamber may have a second inlet configured to permit a substantially laminar flow of air into the airflow path, wherein the second inlet is downstream of the heater. The air flow path and/or openings into the air flow path may be changed to change the particle size of a condensation aerosol produced in the vaporization chamber, and/or to change the amount of visible vapor emitted from the device.

The device may have an inlet adjuster to control the size of the upstream first inlet. The inlet adjuster may be a slide configured to slidably cover the upstream first inlet, or a removable orifice configured to modify the upstream first inlet. The removable orifice, if used, is optionally configured to insert into the upstream first inlet. An opening of the removable orifice may have a cross-sectional area that is less than a cross-sectional area of the upstream first inlet.

The inlet adjuster may be electronically-controlled. A user interface may be provided in electronic communication with the inlet adjuster, with the user interface configured to allow a user to select a condensation aerosol particle size to be produced by the device. Multiple upstream first inlets may be used with the inlet adjuster to change the number of inlets used. The outlet may be in a mouthpiece connecting with the vaporization chamber, and a plurality of inlets upstream of the heater. A baffle may be located upstream of the heater, with the baffle configured to slide within the vaporization chamber, optionally based on a user input.

The device may include a flow sensor electrically connected to an electronic controller which receives and stores an inhalation profile of a user of the device, with the device configured to modify a characteristic of the device based on the inhalation profile. The device may further include a user interface configured to permit a user to modify a characteristic of the device, which may provide more efficient delivery of the condensation aerosol to a deep lung of a user; cause a user of the device to exhale a lower fraction of the condensation aerosol; and/or adjust a sensory effect, such as mouth feel or appearance of the aerosol.

Alternatively, the modified characteristic may be an amount of liquid vaporized by the heater; an amount of current applied to the heater; or a size of the inlet. The flow sensor may be a hot wire or vane type flow meter or a pressure transducer configured to measure an inhalation vacuum. The pressure transducer, if used, may be configured to calculate an inhalation rate. The electronic controller may include a microprocessor and/or a wireless communication device. The device can be configured to calculate optimum parameters for condensation aerosol generation based on an inhalation profile of a user. In this case, the modified characteristics can include the aerosol particle size; the timing of aerosol generation in a user inhalation volume; a resistance to air flow through the device, or an inhalation rate of a user of the device.

The inhalation profile may include inhalation rates of a user over a period of time; a total volume of air inhaled; or a peak inhalation rate of a user of the device. The device may be programmed to automatically modify a characteristic of

the device based on the inhalation profile, or to allow manual modification of a characteristic of the device by a user based on the inhalation profile.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a side perspective view of a cylindrical aerosol generating device.

FIG. **2** is a perspective section view of the device of FIG. **1**.

FIG. **3** is a perspective view of the components of the device of FIG. **1** without the housing.

FIG. **4** is a section view of the device as shown in FIG. **3**.

FIG. **5** is an enlarged perspective view of the heater of the device of FIGS. **1-4**.

FIG. **6** is an enlarged section view of the pump of the device as shown in FIG. **5**.

FIG. **7** is a further enlarged perspective view of the vaporization chamber of the device of FIG. **1**.

FIG. **8** is a diagram showing air flow.

FIG. **9** is a section view showing details of the heater.

FIG. **10** is a side view of the vaporization chamber.

FIG. **11** is a perspective section view of the pump.

FIG. **12** is a perspective view of an alternative pump.

FIG. **13** is a section view of a pump cartridge shown in FIG. **12**.

FIG. **14** is an enlarged section view of the pump of the pump cartridge of FIG. **13**.

FIG. **15** is a perspective section view of an alternative aerosol generating device.

FIG. **16** is an enlarged section view of the device of FIG. **15**.

FIG. **17** is an enlarged section view of the pump shown in FIG. **16**.

FIG. **18** is a section view of components of the pump shown in FIG. **17**.

FIG. **19** is a diagram of a device having a mouth piece, a bypass air, a heater, a slide, inlet holes, and a slide of a device for generating an aerosol.

FIG. **20** is a diagram of a replaceable orifice of a device for generating an aerosol.

FIG. **21** is a diagram of a baffle slider used to modulate air flow and vaporization in a device for generating an aerosol.

FIG. **22** is a diagram of a slider used to modulate air flow and vaporization in a device for generating an aerosol.

FIG. **23** is a computational fluid dynamic model of the air flow velocities of the airway in the device of FIGS. **1-10**.

FIG. **24** is a corresponding computational fluid dynamic model of the pressure drops of the airway.

DETAILED DESCRIPTION

FIG. **1** illustrates an example of an aerosol generating device **30** that is cylindrical and may have a size and shape similar to a tobacco cigarette, typically about 100 mm long with a 7.5 mm diameter, although lengths may range from 70 to 150 or 180 mm, and diameters from 5 to 20 mm. As shown in FIG. **2**, the device **30** has a tubular housing **32** which may be a single piece, or may be divided into two or three separate housing sections, optionally including a battery section **34**, a reservoir section **36** and a heater section **38**. An LED **40** may be provided at the front end of the device **30** with an outlet **52** at the back end of the device **30**.

In the example shown, a battery **56** and a liquid reservoir **60** are contained within the housing **32**. The liquid reservoir **60** contains a liquid, such as a liquid nicotine formulation. A pump **64** is located behind or within the reservoir **60**. The pump (e.g., a piston pump or diaphragm pump) can be mechanically or magnetically coupled to a pump motor **80**. A check valve **82** allows a volume of liquid to flow from the reservoir **60** to the pump **64** for subsequent delivery to a heater **70**. The heater **70** may be in the form of a wire coil. The reservoir may have floating end cap that moves to prevent vacuum conditions in the reservoir as liquid is consumed.

Alternatively, the heater may be provided in the form of a cylinder or plate of a screen or ceramic material, or a honeycomb or open lattice framework. The heater **70** is positioned within a aerosolization chamber **74** leading from an air inlet **78** to a duct **88** connecting to the outlet **52**. The outlet **52** can optionally be in a mouthpiece **84** which is removable from the housing **32**. The inlet **78** can be a single hole or a plurality of holes or slots. As shown in FIG. **10**, the aerosolization chamber **74** may have an arc section **86** below the heater **70** (as oriented in the Figures) to better redirect air flow from perpendicular to the heater to parallel to the heater **70**, as air flows through the aerosolizing chamber **74**, into the duct **88** and out via the outlet **52**. In the duct **88**, the aerosol particles aggregate to the intended size.

The pump motor **80** may be located outside of the reservoir **60** and is mechanically or magnetically coupled to a piston **120** moveable within the pump. In operation, the pump motor **80** moves the piston **120** to deliver a volume of a liquid from the reservoir **60** onto the heater **70**, with the heater **70** vaporizing the liquid. Air flowing through the air inlet **78** causes the vaporized liquid to condense forming an aerosol having a desired particle diameter within the vaporization chamber, prior to the aerosol flowing through the outlet **52**. The pump motor **80** can be a magnetic motor designed to oscillate at a slow frequency (e.g., between 1 and 10 Hz). The volume pumped per stroke is determined by the preset stroke length and the diameter of the piston chamber. The electronic controller **46** can control for variability in battery condition and ensure consistent heating by direct measurement of resistance through the heater to control for changes in battery voltage/charge.

In FIG. **6**, a tube **100** connects the reservoir **60** to the heater **70**. The tube can be metal or an electrically resistive material. The tube **100** can be welded to an end of the heater **70**. As shown in FIG. **7**, the heater **70** is a coil wrapped around an end of the tube **100**, with the heater coil having a length of 2-8 mm. In the example shown, the heater **70** is a 0.2 mm diameter stainless steel wire with about 9 to 12 coil loops concentric with the tube **100**. The heater coil can have an end crimped into or onto an end of the tube **100** to form an electrical connection to the tube and to close off the end of the tube **100**. The section of the tube **100** within the heater **70** may be referred to as a dispensing needle and it is generally concentric with the heater coil.

Referring to FIG. **9**, the tube **100** has an outside diameter of 0.8 to 2 mm or 1 to 1.5 mm. The annular gap spaces the outside diameter of the tube **100** apart from the central section of the heater coil and is typically 0.1 to 0.5 or 1 mm, or 0.2 to 0.4 mm. The spacing between adjacent coil loops is generally 0.2 to 0.8 mm. Consequently, surface tension tends to hold the liquid within or around the heater coil. Also as shown in FIG. **9**, the downstream end of the tube **100** may optionally simply be closed off using a plug **108**, rather than via crimping or welding.

As further shown in FIG. **7**, the tube **100** has tube outlets **102** surrounded by the heater **70**. The outlets **102** may be aligned on a common axis or they may be staggered or radially offset from each other. A portion of the tube **100** between the reservoir **60** and the heater **70** can be sur-

rounded by a sleeve **104** to insulate the tube **100**. The heater coil may be spot welded to the sleeve **104**. In use electrical current flows through the heater **70** by connecting the battery **56** to the tube **100** and the sleeve **104**. In this example, the portion of the heater connected to or sealing the end of the tube as well as the portion of the heater connected to the sleeve **104** can serve as electrical contacts that serve to electrically couple the heater to the battery. The battery can be a 3.8 volt lithium battery with roughly 200 milliamp-hours of electrical energy, generally sufficient to last up to a day of moderate use. The battery **56** is typically cylindrical with the electrodes or contacts **57** and **59** on the flat opposite ends of the battery, and with a potential of 1 to 12 volts.

Referring back to FIG. **6**, the valve **122**A opens and allows liquid to enter the piston chamber **132** when the piston **120** moves away from the input end of the tube **100** and closes when the piston **120** moves towards input end of the tube **100**. Alternating or cycling movement of the piston **120** pumps the liquid from the input end **134** of the tube **100** distally toward an outlet end of the tube **100** at or near the heater **70** surrounding the outlet end **136** of the tube **100**. A second valve **122**B between the input end of the tube **100** and the outlet end of the tube **100** opens when the liquid is being delivered to the heater **70** and closes when the piston **120** is being refilled, to prevent any liquid being pulled backwards from the heater **70** into the piston chamber **132**. Closing of the valve **122**B can be designed to close of the end of the tube **100** once inhalation has stopped, to seal off the reservoir and preclude or prevent any seepage or leaking of liquid onto the heater **70** between puffs or inhalations. The valve **122**B can be moved to the closed position via a magnet **126** or a spring.

The region of the tube **100** over which the piston **120** slides can have an outer diameter of 1 mm. In sliding over the tube **100**, the piston **120** can travel about 0.5 to 1 mm or about 0.75 mm such that a volume of about 0.4 to 0.6 ml of a liquid is pumped with each stroke of the pump, with volumes per stroke of about 0.3 to 0.7 ml typical. With the pump operating at 5 Hz, 2 ml/second of liquid are supplied to the heater **70** in the example shown.

In operation, a user inhales on the outlet **52** of the device **30** such that the inhalation can be sensed by the sensor **50**. Upon detection of the inhalation, the sensor **50** activates the heater **70** through the electronic controller **4**. Additionally, upon detection of inhalation, the electronic controller **46** activates the pump **64** to deliver a volume (i.e., dose) of the liquid from the reservoir **60** into the tube **100**. As shown in FIG. **11**, a sensor **50**A may be located adjacent to the pump, optionally with a sensor probe connecting into the aerosolization chamber **74**.

After the liquid is pumped into the tube **100**, the dose of liquid is moved through the tube by positive displacement from the pump **64**. A chamber section or portion **106** of the tube **100** is disposed within the aerosolization chamber **74** and surrounded by the coil heater **70**. The liquid is pumped out of the tube **100** through the tube outlets **102** in the chamber section **106** of the tube. The outlets **102** act as ejection ports such that the fluid pressure from the pump ejects the liquid through the outlets **102** and onto the heater **70**. The tube **100** can have 1, 2, 3, 4, 5, 6, 7, 8, 9 or 10 tube outlets **102**, with the outlets having a diameter of from 0.2 to 0.5 mm. Three tube outlets **1012** are used in the example shown.

Referring to FIG. **8**, the device **30** is configured to rapidly cool and condense vaporized nicotine mixture into a condensation aerosol. The particles in the aerosol continue to rapidly aggregate and grow due to collisions of the particles into even larger particles while still within the airway. This aggregation continues until a relatively stable aerosol of an appropriately sized aerosol is reached. When the user inhales, air enters the device through inlet holes **200**, which may be located around the periphery of the device about 2.5 cm from the outlet **52** of the device. The inlet holes are typically round and each inlet hole may have a diameter of 0.4 to 1.2 mm. Generally four, six or eight inlet holes are spaced around the circumference of the cylindrical housing. The air is then routed along a channel **202** around the periphery of the airway and flows through two metering slots **204** used to define the inhalation resistance through the device. The slots **204** may be holes with a diameter of 0.8 mm; next the air the air flows through eight slots **206** arranged around the inlet **208** of the airway, which distribute the air over the entire cross section of the airway. Each of the slots **206** may be 8 mm long and from about 0.7 mm to about 1 mm wide.

The air then flows into the entrance of the airway and across the heater, perpendicular to the longitudinal axis of the heater. Finally the air flows through the duct **88** downstream of the heater with the vaporized nicotine mixture and out of the outlet **52**. The inhalation resistance of the device in this example is approximately equal to the flow resistance of a tobacco cigarette, and thereby facilitated a mouth breathing maneuver (i.e., puffing) from the user of the device.

Upon movement of the dose of liquid through the tube outlets **102**, the liquid contacts the heater **70** and is vaporized. The vaporized liquid flows through the chamber **74** in the inhaled air stream i.e., in air flowing between the inlet **78** and outlet **52**. The air flows at a flow rate (about 1 to about 10 lpm) effective to condense the vaporized liquid into an aerosol having a diameter (MMAD) of from about 1 micron to about 5 microns. Subsequently, the flows through the outlet **52** of the device and is inhaled to the deep lungs of the user.

FIG. **12** shows an alternative reservoir cartridge including a pump having piston magnets **130** in between a first valve **122** and a second valve **124**, with the piston magnets **130** used to control movement of the piston.

The device **30** may be designed to produce an aerosol with a particle size in the 1 micron to 3 micron range. Aerosol particles in the 1 micron to 3 micron range can settle in the lung much more efficiently than smaller particles and are not readily exhaled. The devices and methods described here provide an electronic cigarette that can more closely replicate the nicotine deposition associated with tobacco cigarettes. The device **30** can provide a nicotine pharmacokinetics profile (PK) having the sensory effects associated with tobacco cigarette smoking.

The device **30** may be designed to produce particles having a mass median aerodynamic diameter (MMAD) of from about 1 to about 5 μm. The particles can have a geometric standard deviation (GSD) of less than 2. The aerosol can be generated from a formulation having a pharmaceutically active substance. The formulation can be in a liquid or solid phase prior to vaporization. The substance may be nicotine, optionally stabilized using one or more carriers (e.g., vegetable glycerin and/or propylene glycol). The liquid formulation can have 69% propylene glycol, 29% vegetable glycerin and 2% nicotine).

The device **30** can have an flow resistance that is low enough to enable the user to inhale directly into the lung. Low flow resistance can be generally advantageous for deep lung delivery of an substance, such as nicotine, and to enable rapid nicotine pharmacokinetics (PK). tobacco cigarettes

can have a high enough flow resistance to preclude direct to lung inhalation thereby requiring the user to inhale, or puff, by using a mouth breathing maneuver.

The aerosol can be further entrained in an entrainment flow of air supplied by one or more secondary passageways or inlets coupled to the chamber **74**, as further described below relative to FIGS. **19-22**. The entrainment flow of air can entrain the aerosol in a flow effective to deliver the aerosol to the deep lungs of the user using the device. The primary entrainment flow can be from about 20 lpm to about 80 lpm, and the secondary entrainment flow can be from about 6 lpm to about 40 lpm.

The amount of the liquid formulation delivered by the pump may be controlled by setting a pump rate such that a specific pump rate corresponds to a specific volume delivered by the pump. Adjusting the pump rate from a first pump rate to a second pump rate can result in the pump delivering a different amount or volume of liquid formulation. The pump can be set at a first controlled rate such that a first amount of liquid is delivered to the heater which generates a first aerosol having a first size (e.g., diameter) and the pump rate is then changed to operate at a second controlled rate such that a second amount of the liquid is delivered to the heater which generates a second aerosol having a second size (e.g., diameter).

The first and second aerosols can have different sizes (e.g., diameters). The first aerosol can have a size (e.g., diameter) suitable for delivery and absorption into the deep lungs, i.e., about 1 μm to about 5 μm (mass median aerodynamic diameter or visual mean diameter). The second aerosol can have a size (e.g., diameter) suitable for exhalation from a user of the device such that the exhaled aerosol is visible, i.e., less than about 1 μm. Alteration of the rates of the pump can occur during a single puff or use of the device by a user. Alteration of the pump rate during a single use can occur automatically or manually, or during separate uses of the device by a user.

Automatic alteration of the pump rate can be accomplished by electrically coupling the pump to a circuit configured to switch the pump rate during operation of the device. The circuit can be controlled by a control program. The control program can be stored in the electronic controller **46**, which may be programmable. A user of the device can select a desired aerosol size or sets of aerosol sizes by selecting a specific program on the electronic controller **46** prior to use of the device **30**.

A specific program can be associated with a specific pump rate for delivering a specific volume of a liquid formulation in order to produce an aerosol having a desired size. If the user desires an aerosol with a different size (e.g., diameter) for a subsequent use, then the user can select a different program associated with a different pump rate for delivering a different volume of the liquid formulation in order to produce an aerosol with the newly desired size (e.g., diameter). A specific program may be associated with specific pump rates for delivering specific volumes of a liquid formulation in order to produce multiple aerosols having desired sizes. Each of the specific pump rates in a specific program can deliver in succession a specific volume of the liquid in order to produce a succession of aerosols of differing sizes (e.g., diameters) during a single use of the device.

Manual alteration of the pump rate can be accomplished by the user of the device pressing a button or switch **54** on the device during use of the device. Manual alteration can occur during a single use of the device or between separate uses of the device. The button or switch is electrically coupled to the electronic controller **46**. The electronic controller **46** can have program(s) designed to control the operation of the pump such that the pressing the button or switch **54** causes the electronic controller to alter the operation (e.g., pump rate) of the pump in order to affect delivery of a differing volume of the liquid formulation. The user of the device can press the button or flip the switch **54** while using the device or between uses of the device.

The aerosol generating device may be configured to produce an aerosol having a diameter of from about 1 μm to about 1.2 μm. Upon inhaling from an outlet of the device, a user can perform a breathing maneuver in order to facilitate delivery of the aerosol having a diameter of from about 1 μm to about 1.2 μm into the user's deep lungs for subsequent absorption into the user's bloodstream. The user can hold the breath during the breathing maneuver following inhalation of the aerosol and subsequently exhaling. The breath-hold can be for 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10 seconds. The breath-hold can be from about 2 to about 5 seconds. Alternatively, the user can inhale and directly exhale the aerosol having a diameter of from about 1 μm to about 1.2 μm. Inhalation followed by direct exhalation can cause the generation of a visible vapor since a large percentage of the aerosol can be exhaled.

The user may select whether or not the user wants an aerosol generated by the aerosol generating device to be delivered to said user's deep lungs (e.g., alveoli) or be exhaled as a visible vapor. The device **30** may be configured to produce an aerosol size (e.g., aerosol diameter of about 1 micron) such that if a user of the device exhales directly without performing a breath hold, a majority or significant amount of the aerosol is exhaled as a visible vapor. The majority or the significant amount can be more than or greater than 50%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95% or 99%. In this manner, the user of the aerosol generating device can choose during use of the device if they desire deep lung delivery and/or production of a visible vapor.

As shown in FIGS. **13** and **14**, a cartridge **180** having a liquid reservoir **182** includes a cartridge pump **184** connected to an elongated housing **188** having a heater **186** at the tip. The elongated housing **188** can be surrounded by a retractable heater cap **190** provided to protect the heater when the cartridge is not installed into a device **30**. The heater cap **190** may be retracted when the reservoir is inserted or connected to a separate component to form an aerosol generating device. The cartridge **180** can be one component in a multi-component aerosol generating device. The cartridge can be disposable or refillable.

In the example shown in FIGS. **1-9**, the reservoir may be refillable, non-replaceable and configured to hold 2 mg of a nicotine liquid mixture. At a 2% nicotine concentration, this size reservoir provides 40 ml of nicotine. If 40 mg of nicotine is assumed to roughly equal 40 burning tobacco cigarettes in terms of delivered nicotine, then the reservoir in the device in this example lasts between 1-3 days, depending on the intensity and frequency of use. The reservoir may be replaceable. A device **30** having a replaceable cartridge may be designed to: 1.) replace the cartridge only; 2.) replace the pump interior (not the magnetic solenoid with the cartridge); or 3.) replace the heater and pump interior with the cartridge. In this type of device, the non-replaceable portion of the device includes the battery and the electronics. The non-replaceable portion may also contain the vaporization chamber **74**. In each of these configurations, the liquid may be held in rigid container or in a collapsible bag. If used, the collapsible bag may be

constructed from multi-layer laminate material to preserve the purity of the liquid. In operation, as liquid is consumed, the bag collapses.

In methods for aliquoting an substance (e.g., nicotine) to ensure dose-to-dose uniformity, an element having porous materials can wick out fluid at a particular rate in order to measure out a dose to provide dose-to-dose uniformity. A tube, e.g., a capillary tube can be used to measure out a dose, with heat used for ejecting a dose. A material or geometry of a device can be used to measure out a dose providing dose consistency controls for variability in environment and device. Inhalation flow control ensures that variability in inhalations by a user are controlled and corrected for, which can result in dose-to-dose consistency and predictable and desirable aerosol particle sizes.

The liquid may be metered out into a pre-vaporization area in a device (dosing mechanism) through capillary action. The metering can occur between inhalations of a user of a device. Upon inhalation by a user, liquid can be drawn into a vaporization chamber or onto a heater. The liquid can be drawn or metered out into a vaporization chamber or onto a heater upon inhalation by a user.

The vaporization device may include elements for separating out and reducing large aerosol particles to a size that can navigate to the deep lung of a user. In the deep lung, the particles can settle and be rapidly absorbed. For example, the aerosol size control can result in rapid, cigarette-like nicotine absorption, which can help to satisfy nicotine cravings. Aerosol particles having nicotine produced by the device can achieve peak plasma concentrations similar to peak plasma concentrations achieved by smoking a cigarette.

The device **30** may allow the user to vary the flow resistance, to better provide either deep lung delivery or replicate the puffing of a tobacco cigarette. By varying both the size of the inlet that controls the flow through the vaporization region and the size of the bypass or secondary inlet, the user can control the flow resistance through the device and the resultant aerosol particle size. The flow resistance can be varied over time, for example over a month, days, hours, or minutes. The flow resistance can be varied within the same "smoking session."

For example, a user can select a high flow resistance and small particle size to more closely replicate the sensation, perception or the nicotine pharmacokinetics (PK) associated with smoking a tobacco cigarette. A user can select or alter a flow resistance/particle size after several initial deep inhalations. A user can select the flow resistance/particle size to: maximize the nicotine hit or sensation within a series of inhalations (e.g., thereby reducing nicotine cravings), or to focus more on the sensory aspects of the vaping experience, e.g., to produce a large visible cloud of vapor. It can be advantageous in some settings to use a larger aerosol with little or no visible exhaled vapor.

FIGS. **15-18** show an additional example of an aerosol generating device having a tubular housing, an inlet **140**, an outlet **152**, a pump **142**, a reservoir **144**, a heater **146**, a sensor **148** and an airway **150**. As with the device **30** shown in FIGS. **1-9**, the inlet **140** can be a single hole or a plurality of holes. The airway **150** can be a single passageway or configured with a primary passageway and one or more secondary passageways connecting into the primary passageway, generally downstream of the heater.

As shown in **17** and **18**, the pump can be a pump having a first elastomeric membrane **154** which vibrates or oscillates back and forth. The pump can be completely or partially housed within the reservoir **144**. As shown in FIG. **17**, the pump motor **158** can be located adjacent to and outside of the reservoir **60** and can be a solenoid coil. In this design the electrical components of the pump are not exposed to the liquid. The pump **142** can have a magnet **160** held in the first elastomeric membrane **154** and used to control movement of the pump **142**. The pump **142** can further have a second elastomeric membrane **156** that can serve as valve for the liquid to enter a tube that terminates with a dispensing needle as described configured to eject or ooze the liquid onto the heater.

As shown in FIG. **19**, the components of the pump shown in FIG. **16-18** can be held together with pins (e.g., pins **162**). FIG. **18** shows the slots or holes **164** within the pump **142** through which the liquid can pass into the pump and out of the pump into the tube and dispensing needle. The pump motor **158** may be a solenoid coil made from 36 gage magnet wire having 400 wraps and a resistance of around 10-11 Ohms. Generally, 50 to 1000 wraps are suitable using 32 to 38 gauge wire. If the battery supplies a current of about 0.34 amps through the solenoid coil, the pump **142** is driven at about 5 Hz such that the liquid formulation is pumped at about 2-3 mg/second.

FIGS. **19** and **20** show optional modifications of the device **30**. The particle size provided by a device **30** may controlled by controlling the amount of air that entrains the vaporizing nicotine mixture. Control of flow rate through the vaporization chamber **1102** can be accomplished by controlling the size of the primary air inlet(s) **1104** to the vaporization chamber. By controlling the size of the opening, the resulting particle size can be controlled. The user may vary this opening size to control the particle size, and thereby affect the vaping experience in terms of the amount of visible vapor produced by the device, as well as other sensory characteristics.

A user may choose a larger particle size (1-3 um) to more closely replicate the nicotine deposition of cigarettes, as well as vape in a more discrete manner, and in another case they may choose a 0.5 um aerosol to more closely mimic the visual aspects of exhaling a visible vapor, like smoking. This can be accomplished by a user manipulated movable adjusting element such as a slide **1106** or other method of varying the entrance opening size as shown in FIGS. **19** and **22**. The device can also come with exchangeable orifices **1120** that the user inserts into the device as shown in FIG. **20**. Alternatively the device can have a user interface where the user selects the aerosol size and onboard electronics open or close the opening. A baffle slider **1130** may be positioned upstream of a heater **1108**. The baffle slider **1130** can be used to divert air around a heater or vaporization region as shown in FIG. **21**. The elements shown in FIGS. **19-22** may also of course be used in other devices in addition to the device **30**.

A user can switch the inhalation flow resistance and/or particle size characteristics of the vapor to focus more on the sensory aspects of the vaping experience. It can be advantageous in some settings to use a larger aerosol with little or no exhaled evidence where blowing huge plumes and smoke rings is socially unacceptable. In the device of FIG. **19**, the slide **1106** can be moved to cover or uncover a primary air inlet **1104** upstream of the heater **1108**, or a secondary air inlet **1110** downstream of the heater **1108**.

As shown in FIG. **19**, the device **30** can have a vaporization chamber **1102** and one or more upstream primary or first inlets **1104** and a downstream outlet **1112**. An airflow path **1150** leads into the vaporization chamber. The secondary inlet **1110**, if used, allows a substantially laminar flow of air into the airflow path, with the secondary inlet **1110** downstream of the heater **1108**.

The device may be capable of modifying a size of the outlet **1112** and/or the inlet **1104** and/or the secondary inlet **1110** via an adjusting element such as the baffle slider **1130**. The adjusting element may alternatively be a flow restrictor or a fixed or movable baffle, which may be located upstream of the heater, and optionally configured to slide within the vaporization chamber. A vaporization chamber **1102** can be configured to limit a flow of a gas through the airflow path **1150** to permit condensation of a vaporized liquid formulation.

As shown in FIG. **23**, the width and/or cross section of the inlet slots **206** may vary, along with air flow velocity through the airway during inhalation. Air flow velocity in the airway under the center slot may be greater than towards the sides, with typical velocities computed to range from about 0.5 m/s towards the sides up to about 3.5 m/s towards the center. FIG. **24** is a computational fluid dynamic model of pressure drops given in absolute values with 1033 cm (407 inches) H2O representing atmospheric pressure. Inhalation flow resistance in this example was 30 cm H_2O at 1.5 liters/minute. As shown in FIG. **24**, the pressures in the airway between the inlet slots and the heater (998 cm or 395 inches H2O) is computed to be the same as at the outlet **52**.

The solenoid coil can be made from 36 gage magnet wire. In some cases, the solenoid coil comprises 36 gauge magnet wire that has a resistance of around 10-11 Ohms. The 10-11 Ohms resistance of the solenoid coil can be achieved with a solenoid coil having 400 wraps. The battery may supply a current of about 0.34 amps through the solenoid coil such that the pump is driven at about 2 to 10 or 4-6 Hz such that the liquid formulation is pumped at about 1-4 or 2-3 mg/second. Pump frequencies of 1 up to about 100 may be used depending on the pump design. Piston diameters of 0.5 to 5 mm may be used. The magnet in the pump may be a ring magnet with an interior diameter of 1-2 or 1.5 mm, an outside diameter of 4-6 mm or 4.7 mm, and a length of 1-2 mm or 1.5 mm. The distance between successive coils or the pitch of the heater coil may be from about 0.2 to 5 or 0.2 to 0.8 mm.

While preferred embodiments have been shown and described herein, it will be obvious to those skilled in the art that such embodiments are provided by way of example only. Numerous variations, changes, and substitutions can of course be made without departing from the spirit and scope of the invention. The invention, therefore, should not be limited, except by the following claims and their equivalents.

The invention claimed is:

1. A device for generating an aerosol, comprising:

a liquid reservoir for holding a liquid;

a tube made of an impermeable material, the tube having an open first end and a closed second end, and plurality of spaced apart tube outlets in a sidewall of the tube;

a heater wound around the tube, the heater comprising a wire coil surrounding the tube at a position where surface tension holds the liquid within the wire coil, the heater in an aerosolization chamber having one or more air inlets on a first side of the aerosolization chamber for providing air flow across the heater in a direction perpendicular to a longitudinal axis of the tube, the aerosolization chamber having a duct providing an air outlet, the duct on a second side of the aerosolization chamber opposite from the first side, the duct extending in a direction parallel to the longitudinal axis of the tube; and

a pump positioned to pump liquid from the liquid reservoir into the open first end of the tube, with all of the pumped liquid moving out of the tube through the tube outlets, and onto the heater.

2. The device of claim **1** further including a battery having a first electrode electrically connected to a first end of the wire coil and a second electrode electrically connected to the tube.

3. The device of claim **1** further comprising an electronic controller electrically connected to a battery, to the pump, to the heater, and to a sensor adapted for sensing inhalation at the air outlet, with the electronic controller activating the pump and the heater upon sensing inhalation.

4. The device of claim **1** wherein the tube is round, the tube outlets extend radially outward through the sidewall of the tube, and the wire coil is concentric with the tube.

5. The device of claim **1** wherein the duct is offset from a central longitudinal axis of the device.

6. The device of claim **1** further comprising a tubular housing, with a battery at a first end of the tubular housing and the air outlet at a second end of the tubular housing, and with the reservoir between the battery and the pump, and with the pump between the reservoir and an aerosolization chamber.

7. The device of claim **6** with the tube parallel and concentric with the tubular housing.

8. A device for generating an aerosol, comprising:

a tubular housing having a first end and a second end;

a liquid reservoir in the tubular housing for holding a liquid;

an aerosolization chamber in the tubular housing;

a wire coil wound around a hollow tube at a position where surface tension holds the liquid within the wire coil, the hollow tube made of an impermeable material, the hollow tube in the aerosolization chamber, the hollow tube having a plurality of tube outlets through a cylindrical sidewall of the hollow tube;

a pump in the tubular housing at first end of the hollow tube, the pump connected to pump liquid from the reservoir into the hollow tube, and through the hollow tube through the tube outlets, and onto the wire coil; and

one or more air inlets leading into the aerosolization chamber, the one or more inlets on a first side of the aerosolization chamber for providing air flow across the wire coil in a direction perpendicular to a longitudinal axis of the hollow tube, the aerosolization chamber having a duct providing an air outlet, the duct on a second side of the aerosolization chamber opposite from the first side, the duct extending in a direction parallel to the longitudinal axis of the hollow tube.

9. The device of claim **8** with the wire coil concentric with the hollow tube and with wire coil spaced apart from the hollow tube by an annular gap, the hollow tube having a closed second end, wherein all of the pumped liquid moves out of the hollow tube and onto the wire coil through the tube outlets.

10. The device of claim **8** further comprising a second inlet configured to permit a laminar flow of air into the tubular housing downstream of the wire coil.

11. The device of claim **10** further including a fixed or movable baffle or flow restrictor upstream of the wire coil for adjusting air flow into the vaporization chamber to change the particle size of an aerosol produced in the vaporization chamber.

12. A device for generating an aerosol, comprising:

a liquid reservoir for holding a liquid;

a tube made of an impermeable material, the tube having an open first end and a closed second end, and plurality of spaced apart tube outlets in a sidewall of the tube;

a heater coil wound around the tube in a position where surface tension holds the liquid within the heater coil;

a pump positioned to pump liquid from the liquid reservoir into the open first end of the tube, with all of the pumped liquid moving out of the tube through the tube outlets, and onto the heater coil;

the heater coil in an aerosolization chamber having one or more air inlets on a first side of the aerosolization chamber for providing air flow across the heater coil in a direction perpendicular to a longitudinal axis of the tube, the aerosolization chamber having a duct providing an air outlet, the duct on a second side of the aerosolization chamber opposite from the first side, the duct extending in a direction parallel to the longitudinal axis of the tube.

13. The device of claim 12 further including a battery having a first electrode electrically connected to a first end of the heater coil and a second electrode electrically connected to the tube.

14. The device of claim 12 further comprising an electronic controller electrically connected to a battery, to the pump, to the heater coil, and to a sensor adapted for sensing inhalation at the air outlet, with the electronic controller activating the pump and the heater coil upon sensing inhalation.

15. The device of claim 12 wherein the tube is round, the tube outlets extend radially outward through the sidewall of the tube, and the heater coil is concentric with the tube.

16. The device of claim 12 wherein the duct is offset from a central longitudinal axis of the device.

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